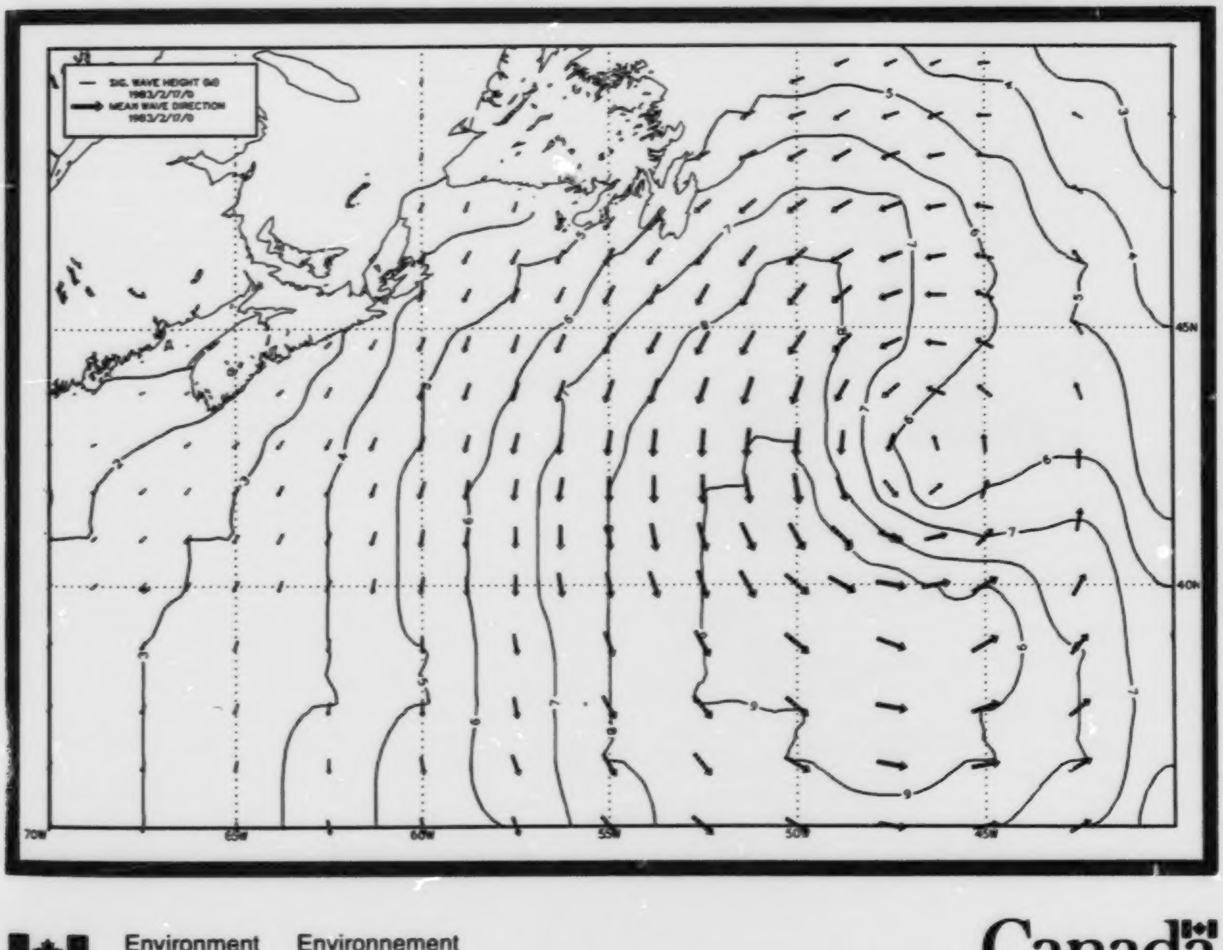
WIND/ WAVE HINDCAST EXTREMES FOR THE EAST COAST OF CANADA

VOLUME I



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WIND/WAVE HINDCAST EXTREMES FOR THE EAST COAST OF CANADA

VOLUME I

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The Authors also wish to record with gratitude the initiation and support from The Canadian Waves Committee, The Canadian Climate Centre, Marine Environmental Data Service, and The East Coast Offshore Operators, particularly Mobil Oil Canada Limited for providing their data and supporting various wave hindcasting and forecasting projects.

EXECUTIVE SUMMARY

Accurate specification of historical wind and wave fields is a critical requirement for many offshore engineering design and operation applications. The objective of this study was to specify, following a hindcast approach, the extreme wave climate offshore the east coast of Canada, by providing accurate surface wind and wave fields in the top-ranked wave-producing storms. The three target areas for the study were The Grand Banks of Newfoundland, The Scotian Shelf, and Georges Bank.

The hindcast approach applied is based on the following main steps: (1) assembly of a comprehensive data base of archived historical meteorological data, measured wave data, and results of previous studies; (2) identification and ranking of historical storm occurrences over as long a period as possible, and selection of hindcast storms; (3) adoption and validation of the most accurate numerical procedures to specify time histories of surface wind fields, surface wave fields, and directional wave spectra in each selected historical storm; (4) hindcast of the top severe storms; (5) analysis of extremes at each hindcast model grid point in the study area to estimate the significant and maximum individual wave height, crest height, and associated wind speed and wave period, associated with given return period or probability of exceedance.

The data base assembly was intended to be exhaustive and utilized all the available resources. The historical period considered in this study extended from 1957 to 1988. The data base for earlier periods is much less extensive and wind fields may not be specified as accurately. The storm selection work was designed to identify storms based on their potential to generate high sea states somewhere within the study area. This task proceeded in several stages. First, all data sources were utilized to develop an initial candidate list of extratropical storms. A total of 532 events comprised this initial list. This list was distilled in several stages, with the aid of both objective storm intensity ranking procedures, and subjective ranking and intensity assessments made by experienced meteorologists and wave

modellers, to produce the final hindcast population of 68 severe events. Since the typical scale of an intense extratropical storm is large with respect of the study area, many selected storms affect more than one of the study sub-areas, and individual storms often overlap two or more areas. At any given site therefore, the study is expected to include the 20-30 top-ranked extreme wave events associated with the extratropical storms during the historical period considered.

Extreme sea states associated with tropical storms were considered only in the Georges Bank. For that area, a comprehensive storm selection was carried out to identify a population of cyclones of tropical origin which had retained tropical characteristics upon crossing Georges Bank. The study historical period was extended back to 1938 due to the rare occurrences of these cyclones and in order to include the exceptional hurricanes which occurred in 1938, 1944 and the early 1950's. A total of 33 historical hurricanes were selected. Only ten (10) highest-ranked, most recent cyclones for which good information was available, were hindcast as a pilot study, in order to gain an understanding of the relative importance of tropical and extratropical storm generated extreme sea states in Georges Bank. No extremal analysis of tropical cyclone hindcast results was carried out.

Wind and wave hindcast methodology adapted in this study has already undergone considerable refinement and validation in several previous studies. The method used for hindcasting wind fields for the selected storms is based on man-machine mix techniques using a blend of surface pressure analysis and kinematic analysis wind fields. In this method the specification of 6-hourly wind fields in each storm includes a complete reanalysis of the evolution of the surface pressure fields, calculation of objective wind fields using a proven calibrated marine planetary boundary layer model, and finally kinematic analysis to provide winds of the highest accuracy achievable for the available data. The wave hindcasts were carried out using the ODGP spectral wave model adapted to the North Atlantic basin on a high-resolution nested grid, with temporal resolution of 2 hours and spatial resolution of an average of about 85 km. It should be noted here that the ODGP model used in this study is a DEEP WATER wave model, and therefore the results should be treated accordingly.

A substantial validation of model predictions was included in this study, involving comparison of hindcasts of 10 extreme storms against measured data at several sites in the study area. The comparison of hindcast deep water model storm peak sea states generated in this study against measured storm peaks provided a mean difference (bias) of + 0.53 m and a scatter index of 13.2%. In order to investigate the source of the increased positive bias found in the present hindcasts, the hindcasts were adjusted in an approximate way (using a TMA scaling) for shallow water attenuation at the shallow water sites before comparison. The procedure was found to change the sign of the mean error and to decrease the scatter index slightly. The overall scatter index of 13.2% in wave height noted above (11.2% if hindcast data are "adjusted" for shallow water) is at the lower end of the of such indices reported for similar hindcast studies, using most sophisticated modelling techniques.

Finally, an extremal analysis was carried out using site-specific hindcasts of peaks-over-threshold (POT), at each grid point of the fine mesh model grid system (total 118 points). At each point, the threshold was determined by allowing only the top-ranked 30 storms of the 68 storms hindcast. Extremes of significant wave height (H_s), maximum individual wave height (H_m), and crest height (H_c) were specified at all grid points within the study area, using Gumbel extreme value distribution fitted by the method-of-moments (MOM) for given return periods (up to 100 years or probability of exceedance of 0.01).

The analysis included sensitivity studies on threshold limits, distribution function, and fitting scheme. The maximum wind speed associated with extreme sea state was also calculated. The peak period (T_p) associated with extreme sea state was estimated from the correlation analysis of the T_p and H_s pairs. The main extremal analysis considered hindcast peaks regardless of wave direction. The hindcast population was too small to warrant a full extremal analysis stratified by directional sectors of wave approach.

RÉSUMÉ

Pour nombre d'applications d'exploitation et de conception au large des côtes, il faut une spécification précise des champs historiques de vents et de vagues. Cette étude visait à spécifier, par des prévisions a posteriori, le climat des vagues extrêmes au large de la côte est du Canada, en fournissant des champs précis de vagues et de vents de surface dans les tempêtes productrices de vagues classées au sommet. Les trois zones étudiées étaient les Grands Bancs de Terre-Neuve, la plate-forme Scotian et le banc George.

La méthode de prévision a posteriori repose sur ces principales étapes : 1) constitution d'une base complète de données météorologiques historiques archivées, de mesures des vagues et de résultats d'études antérieures; 2) détermination et classement des phénomènes historiques de tempêtes sur la période la plus longue possible et sélection des tempêtes prévues a posteriori; 3) adoption et validation des méthodes numériques les plus précises pour spécifier le comportement, dans le temps, des champs de vent de surface, des champs de vagues de surface et des spectres directionnels de vagues dans chacune des tempêtes historiques choisies; 4) prévision a posteriori des plus violentes tempêtes; 5) analyse des extrêmes à chaque point de quadrillage du modèle de prévision a posteriori pour la zone étudiée, afin d'estimer la hauteur significative et maximale des vagues et des crêtes individuelles, la vitesse du vent et la période des vagues correspondantes, liées à la période de récurrence donnée ou à la probabilité de dépassement.

La constitution de la base de données, censée exhaustive, a fait appel à toutes les ressources disponibles. La période historique étudiée dans cette étude allait de 1957 à 1988. La base des données, pour les périodes antérieures, est nettement moins vaste et l'on ne peut pas spécifier les champs de vents avec autant de précision. La sélection des tempêtes visait à déterminer les tempêtes suivant leur capacité d'engendrer des états de grosse mer dans la zone étudiée. Cette tâche s'est accomplie en plusieurs étapes. Tout d'abord, on a utilisé toutes les sources de données pour dresser une liste initiale de présélection des tempêtes extratropicales. Cette liste en comprenait 532. On a écourté

cette liste en plusieurs étapes, grâce à des méthodes objectives de classement de l'intensité des tempêtes et aux évaluations subjectives de l'intensité et du classement effectuées par des météorologues et des spécialistes de la modélisation des vagues expérimentés. On a ainsi obtenu une liste de prévision a posteriori comptant 68 phénomènes violents. Vu que l'étendue type d'une intense tempête extratropicale est grande par rapport à la zone étudiée, nombre de tempêtes frappent plus d'une des sous-régions étudiées et, souvent, les tempêtes individuelles se chevauchent dans deux ou plusieurs zones. En conséquence, à tout emplacement donné, l'étude comprend en principe les 20 à 30 phénomènes extrêmes de vagues classés au sommet et liés aux tempêtes extratropicales pendant la période historique étudiée.

Ce n'est que pour le banc George qu'on a étudié les états extrêmes de la mer liés aux tempêtes tropicales. Pour cette zone, on a procédé à une sélection complète des tempêtes pour identifier une population de cyclones d'origine tropicale ayant conservé des caractéristiques tropicales en traversant le banc George. Vu la rareté de ces cyclones et pour inclure les ouragans exceptionnels survenus en 1938, en 1944 et au début des années 1950, on a fait remonter la période historique d'étude à 1938. Au total, on a sélectionné 33 ouragans historiques. Seuls dix des plus récents cyclones classés au sommet pour lesquels on disposait d'information ont été prévus a posteriori sous forme d'étude pilote, afin de comprendre l'importance relative des états extrêmes de la mer attribuables, au banc George, aux tempêtes tropicales et extratropicales. On n'a pas analysé les extrêmes pour les résultats de prévision a posteriori des cyclones tropicaux.

Les méthodes de prévision a posteriori des vents et des vagues, adaptées à cette étude, ont déja fait l'objet d'améliorations et de validations considérables dans plusieurs études antérieures. La méthode utilisée pour prévoir a posteriori les champs de vents des tempêtes sélectionnées repose sur des techniques mixtes homme-machine et fait appel à une conjonction d'analyse de la pression de surface et d'analyse cinématique des champs de vents. Dans cette méthode, la spécification des champs de vents de chaque tempête, sur six heures, comprend une nouvelle analyse complète de l'évolution des champs de pression de surface, le calcul des champs objectifs de vents à l'aide d'un modèle étalonné, qui a fait ses preuves, pour l'étude de la couche limite planétaire et maritime, ainsi que, finalement, l'analyse cinématique, afin de de déterminer les vents avec le plus de précision possible, compte tenu des données disponibles. Pour la prévision a posteriori des vagues, on a utilisé le modèle spectral ODGP de vagues adapté au bassin de l'Atlantique Nord sur un quadrillage emboîté à haute résolution, la résolution temporelle étant de 2 heures et la résolution spatiale moyenne d'environ 85 km. Notons qu'on a ici utilisé un modèle ODGP d'étude des vagues POUR EAUX PROFONDES et qu'il convient de traiter les résultats en conséquence.

Cette étude comprenait une importante validation des prévisions des modèles, où entrait en jeu la comparaison des prévisions a posteriori de dix tempêtes extrêmes avec les données mesurées à plusieurs emplacements de la zone étudiée. En comparant les états de la mer au point culminant des tempêtes prévus a posteriori dans cette étude par le modèle pour eaux profondes avec les points culminants mesurés des tempêtes, on a dégagé un écart moyen (erreur systématique) de +0,53 m et un indice de dispersion de 13,2 %. Afin d'étudier la source de l'erreur systématique positive accrue, relevée dans les présentes prévisions a posteriori, on les a rectifiées d'une façon approximative (avec ajustement d'échelle TMA) avant la comparaison, afin de tenir compte de l'atténuation pour eau peu profonde aux emplacements à eau peu profonde. On a alors constaté que le signe de l'erreur moyenne changeait et que l'indice de dispersion baissait un peu. Suivant les techniques de modélisation les plus perfectionnées, l'indice global de dispersion, de 13,2 %, de la hauteur des vagues susmentionné (11,2 %, si les données de prévisions a posteriori sont "rectifiées" pour eau peu profonde) correspond aux valeurs faibles d'indices du même genre signalés pour des études analogues de prévisions a posteriori.

Enfin, on a analysé les extrêmes en recourant aux prévisions a posteriori de crêtes sur seuils (CSS) propres à tel ou tel emplacement à chaque point du fin quadrillage d'un modèle (118 points au total). A chaque point, on a déterminé le seuil en n'acceptant que les 30 tempêtes classées au sommet des prévisions a posteriori de 68 tempêtes. En observant la distribution Gumble des extrêmes ajustée par la méthode des moments (MDM) pour des périodes de récurrence données (jusqu'à 100 années ou probabilité de dépassement de 0,01), on a spécifié, à tous les points de quadrillage de la zone étudiée, les extrêmes des hauteurs significatives de vagues (H_s), des hauteurs maximales des vagues individuelles (H_m) et des hauteurs de crêtes (H_c).

L'analyse comprenait des études de sensibilité sur les limites de seuils, la fonction de distribution et la formule d'ajustement. En outre, on a calculé la vitesse maximale du vent liée à l'état extrême de la mer. Pour estimer la période de crête (T_p) liée à l'état extrême de la mer, on a fait appel à l'analyse de corrélation des éléments T_p et H_s qui vont ensemble. La principale analyse des extrêmes a étudié les crêtes des prévisions a posteriori indépendamment de la direction des vagues. La population des prévisions a posteriori était trop faible pour justifier une analyse intégrale des extrêmes divisée en secteurs de direction de l'approche des vagues.

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ACRONYMS AND ABBREVIATIONS

AES	Atmospheric Environment Service
AWC	Atlantic Weather Centre, Bedford (now MWC: Maritimes Weather Centre)
CCAH	Hydrometeorology and Marine Division
CCC	Canadian Climate Centre
CCT	Computer Compatible Tape
COADS	Comprehensive Ocean-Atmosphere Data Set
COGLA	Canada Oil and Gas Lands Administration
DSS	(Department of) Supply and Services Canada
EB	Georges Bank
GB	The Grand Banks of Newfoundland
GTS	Global Telecommunication System
LFM	Limited Area Fine Mesh Model of NOAA
MANMAR	Manual of Marine Weather Observing
MCL	MacLaren Plansearch Limited
METOC	Meteorological and Oceanographic Centre, Halifax
MEDS	Marine Environmental Data Service
MPBL	Marine Planetary Boundary Layer
MPL	MacLaren Plansearch Limited
MRDC	Mobil Research and Development Corp., Dallas
NCDC	National Climatic Data Center
NDBO	National Data Buoy Office, NOAA
NH	Northern Hemisphere
NMC	U.S. National Meteorological Center
NOAA	National Oceanographic and Atmospheric Administration
NWP	Numerical Weather Prediction Model
ODGP	Ocean Data Gathering Program Spectral Ocean Wave Model
OWI	Oceanweather Inc.
OWS	Ocean Weather Stations
PBL	Planetary Boundary Layer
PMD	Project Management Document
SOWM	Spectral Ocean Wave Model of the U.S. Navy
SS	Scotian Shelf
WES	Waterways Experiment Station
WMO	World Meteorological Organization
WP	Word processed, processing

1.0 INTRODUCTION

1.1 STUDY OBJECTIVES AND SCOPE

The main objective of this study was to specify, following a hindcast approach, the extreme wave climate in the Canadian east coast offshore exploration areas. More specifically the study area covered the Grand Banks of Newfoundland, the Scotian Shelf and Georges Bank (Figure 1). The study was intended to provide accurate surface wind fields and wave fields in the top-ranked east coast storms and use these data to provide design wave parameters for a given risk level (or return period).

The severe storms affecting the east coast of Canada are mainly extratropical cyclones. As a result, the storm selection task identified potentially severe wave-producing extratropical storms in the study area. The most severe storms, selected from the period 1957 to 1988, were hindcast using calibrated wind/wave hindcast methods adapted to the North Atlantic basin on a grid system able to resolve the scale of extratropical wind systems. The first generation ODGP spectral wave model was used in this study.

In addition, the Georges Bank area is affected by tropical cyclones. Therefore, a separate storm selection activity was carried out. In this case, a population of cyclones of tropical origin, which had retained tropical characteristics upon crossing Georges Bank, was identified from all available data sources. The historical period covered goes back to the late 1930's. A special version of the ODGP hindcast model was used with a much finer grid than that used for the extratropical storm hindcast. The tropical cyclone hindcast procedures and model used are described in detail in a separate volume of this report (Volume II). However, the final list of the selected cyclones and hindcast results are presented in this report.

In this study, the wind hindcasting was based on the method developed at Oceanweather Inc. (e.g. Cardone, 1980). The ODGP (Ocean Data Gathering Program) Spectral Ocean Wave Model was used to hindcast the top storm events. A fully directional spectral wave product was provided for these storms at selected grid points. An extremal analysis was then carried out to determine the probable extreme parameters for given recurrence intervals (e.g. 2, 5, 10, 25, 50 and 100 year return periods).

The application of the hindcast method included the following main steps:

(1) survey of historical meteorological and oceanographic data, to identify the most severe storms of the relevant types which have occurred within as long a period of history as possible;

(2) the specification of surface wind fields on a discrete grid for each storm;

(3) the numerical hindcast of the time history of the sea state on a grid of points representing the basin, for each storm;

(4) calculation of the expected extreme wave heights and associated properties for each storm at each point; and

(5) extrapolation of the hindcast maxima through the process of extremal analysis, which provides estimates of extremes associated with specified return periods (the average interval in years between events equal to or greater than the associated extremes).

The results of the hindcast were saved on computer tapes for inclusion in the AES climatological database for future applications.

1.2 STUDY AREAS

The study areas, which cover most of Canadian east coast offshore exploration areas, were:

a) the Grand Banks of Newfoundland (GB); area bounded by the 500 m contour up to 50°N latitude;

b) the Scotian Shelf (SS); area west of Laurentian channel and bounded by the 3000 m contour up to the edge of Georges Bank; and

c) Georges Bank (EB).

Georges Bank was originally included as part of Scotian Shelf region. However, this area was later treated separately due to the occurrence of both tropical and extratropical cyclones. The study areas are outlined in Figure 1.1 and Figure 1.2 which also shows the model grid.

1.3 HISTORICAL PERIOD COVERED

Previous experience with the historical meteorological database of the N.W. Atlantic Ocean basin supported selection of storms from the past 31 years. The database for earlier periods is much less extensive and wind fields may not be specified as accurately. In addition, the CMC charts on microfilm go back only to 1957. Therefore, the historical period considered for extratropical storms extended from 1957 to 1988. On the other hand, the extended period 1938-1988 was included in the Georges Bank tropical storm selection since the most extreme East Coast tropical storms of this century have already undergone some intensive analysis in prior studies and since a longer period was needed to get a reasonable population for extremal analysis.

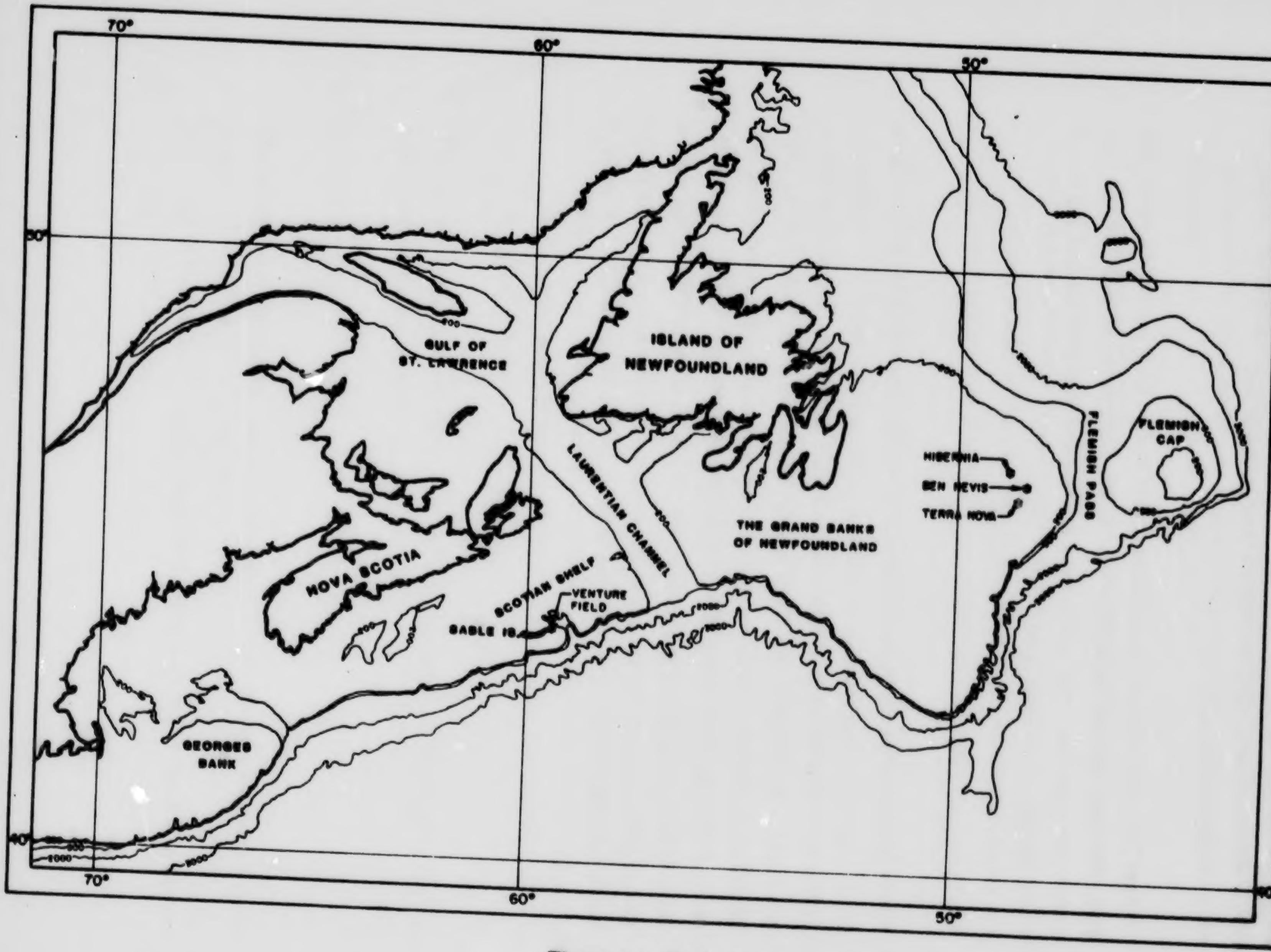


Figure 1.1 Study Area

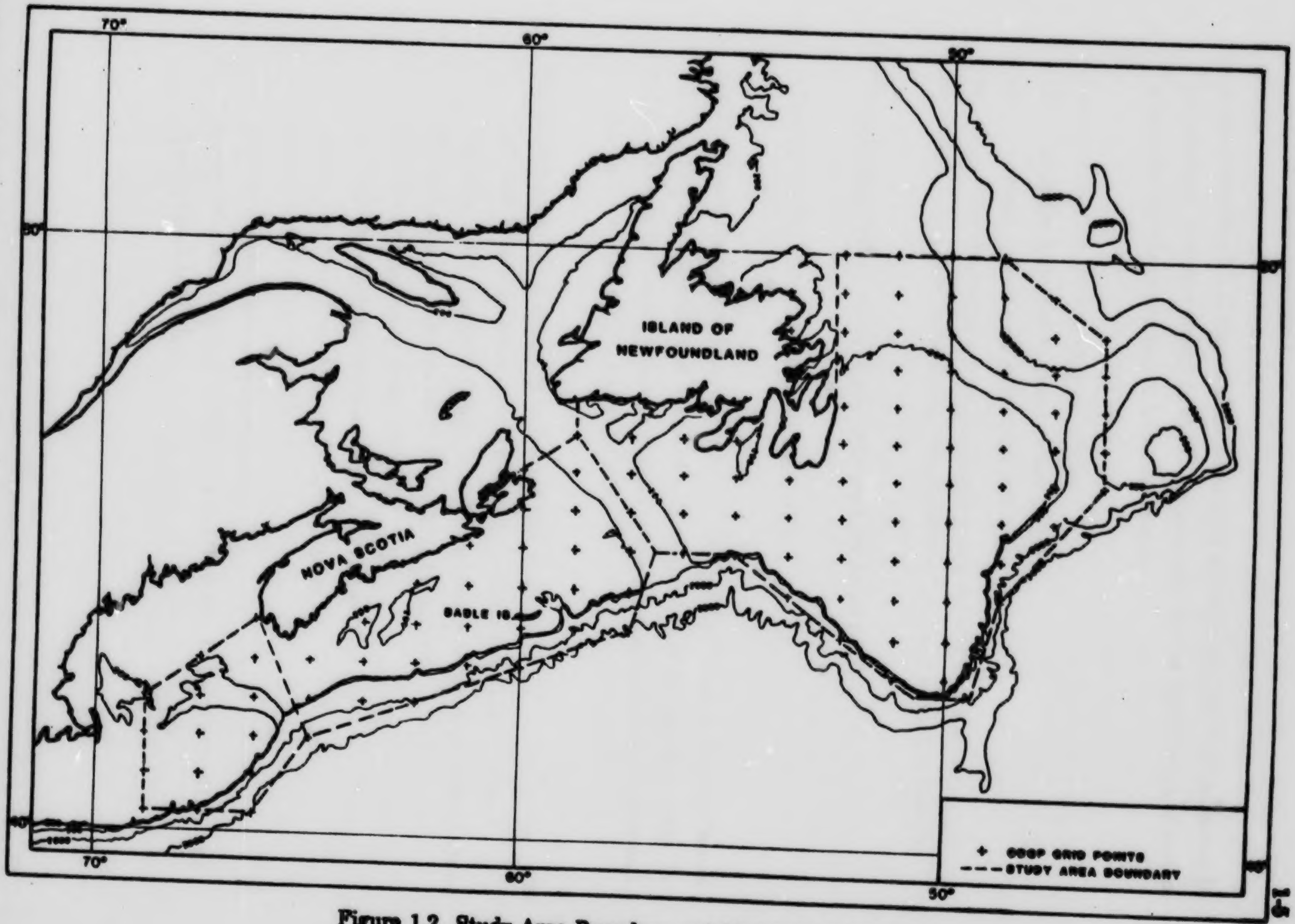


Figure 1.2 Study Area Boundary and Model Grid Points

2.0 DATA BASE ASSEMBLY

A comprehensive file of historical meteorological and seastate data was assembled for the selection of severe storms in the study area and for the specification of surface wind fields for the production of historical storms.

The data fall into the following categories:

(1) archived historical surface weather maps;
(2) weather observations from ships in transit;
(3) weather observations from stationary platforms and land stations;
(4) wave data from instruments, visual observations, and numerical models.

The principal sources accessed and data used are listed below.

2.1 ATMOSPHERIC ENVIRONMENT SERVICE

The Hydrometeorology and Marine Division (CCAH) of the Canadian Climate Centre (CCC), AES, has collected and compiled a large number of marine data sets. In addition, several software packages are also available to access these data bases and analyze the data (e.g., MAST, LAST, DUST).

The following AES data sets were utilized in this study:

- Atlantic Weather Centre (AWC) microfilm weather maps (1970-1986)
- Canadian Meteorological Centre (CMC) microfilm weather maps (1957-1986)
- COADS ship observations up to end of 1979 (1854-1979)
- Canadian co-operating ships 1980-1987
- drill rigs operating in Canadian waters (1972-1987)
- weekly ice charts from AES Ice Central, Ottawa
- NOAA buoy data (1972-1986)
- AES land observations (1953-present)
- Ocean Weather Stations (OWS) Bravo (1946-72), Delta (1946-1972), and Charlie (1946-1981) data

- Sambro (1949-1966), Lurcher (1949-1969) lightships data
- SOWM wind and wave hindcast (1956-75)
- WES wind and wave hindcast (1956-75)
- Geostrophic Wind Climatology (GWC) data set (1946-1986)

A description of the above data bases, file format, access, etc. can be found in the marine climate directory CCAH 90-1 (1990).

A complete physical copy of the AWC microfilm file of 6-hourly surface weather maps from 1970 to 1986 was obtained, to facilitate repeated referral for storm selection and wind analysis.

A copy of CMC microfilm 6-hourly surface weather maps was obtained for the periods corresponding to the most severe storms (some 85 storms) identified in the storm selection procedures.

2.2 NATIONAL CLIMATIC DATA CENTER, NOAA

Two data types were assembled from NCDC/NOAA: surface weather map series, and digital files of historical ship reports.

a) Surface Weather Maps

The following microfilm of weather maps series were acquired to provide continuous files of maps from May 1954 through June 1987:

(1) NCDC File MF915, which contains 3-hourly North American Surface Analyses produced originally at the U.S. National Meteorological Center (NMC) in real time;

(2) NCDC File MF917, which contains 6-hourly Northern Hemisphere Surface Analyses produced at NMC in real time (so-called Final Analysis). This file contains the late ship reports as the data cut-off to analysis time is about 4 hours as opposed to about one hour cut-off for the NCDC File MF915.

b) Synoptic Ship Reports

Extensive collections of historical surface weather observations from ships reside in three separate magnetic tape archive files available at NCDC. The NCDC files consist of the following:

(1) "Marine Deck" files, which cover the period 1854-1969;

(2) "Decade of the 1970's," which covers the period 1970-1979;

(3) "Tape Deck 1129," which covers the period 1980 - present, and which consists mainly of recorded ship reports transmitted over the Global Telecommunications System (GTS) in real time, and ship reports punched from ships' logs received at the NCDC within about 3 months of real time.

These tape files were used to update AES ship observation files through 1987, over the domain of the study area to ensure that the latest collections assembled by NCDC were available for use in the kinematic analysis.

The first two ship files above are also part of the COADS file, which, as noted above, is available from AES.

2.3 OFFSHORE OPERATORS

"Daily Observation Logs" for rigs were obtained for selected storms. These include both meteorological and sea-state observations (hourly to 3 hourly). Detailed wave buoy measurements from buoys deployed nearby offshore rigs were obtained from MEDS (see below). Regular 3-hourly weather reports from rigs are also included in the AES data base.

2.4 MOBIL VENTURE/HIBERNIA STUDIES

With the conditional release by Mobil Oil Canada Ltd. of data from their Hibernia and Venture hindcast studies, large archive files of data generated in these studies became available. In addition to the formal project Final Reports, two specific project data sources were referred to extensively;

(1) candidate and final populations of historical storms specific to the Hibernia and Venture sites, including for each member of each population, various storm screening parameters extracted from historical weather maps; and

(2) the "storm wallets", produced for each storm hindcast in these studies, containing reanalysed surface pressure charts, ship report plots, continuity analyses, kinematic analyses, and hard copy listings of wind and wave hindcast runs.

2.5 MacLAREN PLANSEARCH/OCEANWEATHER INC. DATA ARCHIVES

A number of useful products were available to this study from related activities carried out by the above consultants within the past few years;

(1) 6-hourly hand-drawn surface analysis charts prepared at MPL's weather office in real time were utilized for selected storms from 1981 to the present;

(2) MPL archived rig data (both meteorological and oceanographic). These files of 3-hourly, and in some cases hourly, observations were extracted from MANMAR (WMO) observation logs and waverider buoy measurements and placed into computer files. These observations were used both for the production of the kinematic analyses and for the validation of the wind and wave fields of the verification storms;

(3) OWI real-time synoptic charts, produced as part of its real-time East Coast analysis/forecast operation; and

(4) the ODGP 3-year (Oct. 1, 1983 - Sept. 30, 1986) hindcast data for the East Coast, see MacLaren Plansearch Limited (1988).

2.6 METOC CENTRE

Every 12 hours, the Canadian Forces Meteorological and Oceanographic Centre (METOC) in Halifax, Nova Scotia produces significant wave height analysis and prognosis fields for Canadian waters. The analyzed fields are based on available wave reports together with Bretschneider-derived subjective wave information obtained from METOC's own surface analysis products. The METOC wave height analyses have been found to be of consistently high quality. A copy of the METOC microfilm archive of 00Z and 12Z analysis charts from June 1971 to December 1986 was obtained for use in storm selection.

The METOC wave analyses are available in digital form in two data sets. The first contains information every 12 hours on the maximum wave height in a 5° latitude/longitude square, plus the associated period and direction. The second contains wave height information only at the centre point of each 5° latitude/longitude square. The former data set extends from 1970-87, the latter from 1972-80. Both data sets are part of AES database which was accessed using the MAST system and used in the storm selection task.

2.7 MARINE ENVIRONMENTAL DATA SERVICE

The Marine Environmental Data Services Branch (MEDS) of the Department of Fisheries and Oceans has been largely responsible for collection, retrieval and analysis of data from the majority of wave measurement programs in Canadian waters since 1970. The bulk of MEDS wave data are from non-directional waverider buoys. A typical waverider observing program has a buoy located close to a nearby vessel, drilling platform, or land station where the radio signal from the buoy is received and recorded on tape. The newer generation has satellite transmission (e.g. ARGOS, GOES) where wave information is transmitted to MEDS headquarters on a regular basis (e.g. every 3 hours). The digital wave database archived at MEDS can be accessed from remote terminals or data can be obtained on magnetic tapes.

The above data sources were used in the identification and selection of the most severe storms in the study area as described in the following section.

3.0 STORM CLASSIFICATION AND STORM SELECTION

The single most important property of candidate storms in this study was the potential for generation of severe sea states somewhere within the study area. The process of identifying candidate storms was greatly complicated by the large size of the study areas, unlike previous extreme wave climate studies, which generally considered specific sites. Therefore, it was necessary to explore in this study many different possible indicators of storm severity.

Previous experience has shown that the most effective screening parameter is simply the maximum integrated wind speed (integration time 12 to 24 hours) in the fetch zone of wave generation directed toward the target site or area. Unfortunately, this parameter is not usually directly available as a screening parameter in archived meteorological data, except where continuous measured series are available, e.g. from Ocean Station Vessels in the North Atlantic or islands and coastal stations of low relief (e.g. Sable Island). Therefore, indirect estimates of storm wave generation potential derived from ship, coastal, or island wind observations, and surface pressure patterns must be used. Ultimately, some subjective assessments by meteorologists with experience in correlation of meteorological storm properties with wave generation must also be used in the ranking process, especially in the final selection of the most severe storms.

Indirect estimates of storm wave generation potential were used in the study to identify potentially severe storms. These included maximum sea-level pressure gradients, storm central pressure, and deepening rate. Szabo et al. (1989), were able to demonstrate objectively that the indirect procedures using parameters gleaned from operational Northern Hemisphere 6-hourly surface analysis correctly selected all storms which exceeded the wave height threshold of the extremal analysis at a given target point.

That study also showed that the spatial structure of storms was very important in the selection of extreme events for an area as opposed to a point location.

Storm frequency is relatively high in the study areas, and the size of the target population of storms to be hindcast was originally 50 storms. This number was based upon the assumption that about 30 extreme events are required to adequately define the design wave climate for each of the Grand Banks and Scotian Shelf regions, with an assumed overlap of about 10 storms. A list of the top 30 storms was also targeted for Georges Bank, including tropical storms, with an expected overlaps of about 20 storms between Georges Bank and the Scotian Shelf. As a result of smaller overlap, the storm population was increased to a final total of 68 storms.

In previous hindcast studies for Hibernia and Venture, which concerned specific sites within the study areas, there were easily identified over 100 candidate storms in each area. For this study, after considering all potential sites within the study areas, several hundreds of storms were identified; the challenge of this task was to reduce a candidate list of several hundred storms by nearly an order of magnitude.

This task proceeded in several steps. First, all assembled data sources and previous studies were utilized to develop a comprehensive list of candidate extratropical storms in the study areas (GB, SS & EB). This list was then reduced in several stages to refined storm lists, with the aid of both objective storm intensity ranking parameters and subjective ranking and intensity assessments.

In summary, the storm selection is accomplished in three main steps:

1) Selection of candidate population of severe storms;
2) Storm verification and cross-checking between data sources;
3) Storm ranking and final selection.

The storm population was then stratified into different types capable of generating extreme waves on the Grand Banks, Scotian Shelf and Georges Bank.

3.1 PREVIOUS STUDIES

Lists of severe storms off Canada's east coast have been produced in a number of different studies, some with objectives similar to this study. A brief summary of the storm selection criteria for relevant studies is given below.

1. CCC Report # 84-13, 1984, "Severe storms off Canada's East coast; a catalogue summary for the period 1957 to 1983"; Lewis and Moran (1984).

Period Covered:	1957-1983
Area:	40°-75°N, 45°-70°W
Selection Criteria:	highest reported sustained winds ≥ 55kts)
Data Sources:	AES database (COADS, Can. ships, rigs, land, buoys, etc.), microfilm of AES surface weather charts, Marine Weather logs.
No. of Storms:	125 events.

2. ESRF Report # 020, 1986, "Climatology of Severe Storms Affecting Canadian East Coast Areas"; Brown et al. (1986).

Period Covered:	1946-1982
Areas:	Seven areas off east coast including Scotian Shelf and the Grand Banks
Selection Criteria:	large waves
Data Sources:	- SOWM and WES wave hindcasts (1956-75) - METOC wave charts (1972-1982) - NEDN data set 1974-1982 - ship observations - measured waves 1970-1982
No. of Storms:	Top 30 storms in each area based on wave hindcasts using SMB method.

3. Mobil Hibernia Wave Hindcast Study (HWHS), MPL and OWI (1985)

Period Covered:	1951-1984
Area (site):	45°-50°N, 45°-50°W, Hibernia site
Selection Criteria:	High wave generating events
Data Sources:	NMC/NOAA surface charts, ship reports, and land station data for hindcasting wind fields, and using ODGP model for wave hindcast
No. of Storms:	top 32 events.

4. Mobil Venture Development Project, Met/Ocean Criteria Study, MPL & OWI (1985)

Period Covered:	1955-1982
Study Area:	43°-45°N, 58°-63°W (Venture Site)
Selection Criteria:	high wave generating events, wind direction
Data Source:	Sable Island hourly winds, NMC microfilms, ship reports, etc.
No. of Storms:	25 storms.

A compiled list of storms identified in the above studies is given in Appendix A.

3.2 IDENTIFICATION OF POTENTIAL SEVERE STORMS

The development of the initial coarse list of potentially severe wave-producing storms consisted of examining the data bases listed in the following sections. For each storm identified, the starting and ending dates and selected wind and wave values, including maximum wind speed, duration of wind speed above the threshold, and maximum significant wave height measured, observed or predicted from previous hindcast studies, were abstracted from the data records.

3.2.1 AES Digital Data Bases

Potentially severe storms in the period 1957-1987 were identified by using the MAST system to scan the AES digital data bases listed in Chapter 2 (ships, rigs, buoys, etc.). All wind and wave data greater than or equal to specified thresholds were extracted. The thresholds were established upon examination of wind and wave records, and selected to be in the range of 34-40 knots for wind speed and 6 metres for significant wave height. The areas for each of the regional scans are shown in Appendix A. Table 3.1 provides a summary of the data sources, threshold values, and number of events yielded from each screening run. A complete list of the storm events, cross-referenced to previous studies, is given in Appendix A.

Table 3.1: Storm Selection Criteria

SCOTIAN SHELF (including Georges Bank)

Run No.	Data Source	Threshold	No. of Events	Period
1.	COADS, NOAA Buoys, Canadian Ships, OWS	Winds ≥ 40 knots Waves ≥ 10 metres	80	57-86
2.	Rig Obs. & Sources listed in 1 above	Winds ≥ 34 knots Waves ≥ 6 metres	159	57-86
3.	COADS, NOAA Buoys, Canadian Ships, OWS	Waves ≥ 6 metres Winds ≥ 34 knots	150	57-86
4.	Sambro & Lurcher Obs.	Winds ≥ 34 knots	30	57-69
5.	METOC Digitized Charts	Waves ≥ 6 metres	86	72-86
6.	MEDS Waverider	Waves ≥ 6 metres	43	70-85
GRAND BANKS				
1.	COADS, NOAA Buoys Canadian Ships & OWS	Winds ≥ 40 knots Waves ≥ 6 metres	67	57-86
2.	COADS, NOAA Buoys Canadian Ships & OWS	Winds ≥ 34 knots Waves ≥ 6 metres	162	57-86
3.	Rig Obs. & Sources listed in 1 above	Winds ≥ 34 knots Waves ≥ 6 metres	37	70-86
4.	METOC Digitized Charts	Waves ≥ 6 metres	81	72-86
5.	MEDS Waverider	Waves ≥ 6 metres	47	70-85
GEORGES BANK				
1.	COADS, NOAA Buoys Canadian Ships & OWS	Winds ≥ 34 knots Waves ≥ 6 metres	67	

NOTES:

- With the exception of MEDS waverider data, all above runs were made using AES MAST system.
- Thresholds were arbitrarily selected.

3.2.2 MEDS Waverider Buoy Measurements

All waverider buoy data compiled by MEDS for the study area from 1970 through 1985 were screened to identify all events with significant wave height (H_s) greater than or equal to 6 metres. A separate list of potential candidates was identified. The list identifies the area starting and end dates of storm, MEDS station number, and the corresponding maximum H_s measured in the area. This list was then blended with the above list (identified in 3.2.1).

3.2.3 METOC Digital Wave Archive

As noted in Chapter 2, AES has maintained a data base of the digitized METOC wave height charts. Using the MAST system, all events with significant wave height H_s greater than or equal to 6 metres were identified (Table 3.1). Maximum wave heights in the study area were added to the above list as shown in Appendix A.

3.2.4 Previous Studies

Each of the studies identified in Section 3.1 produced coarse lists of candidate storms for the specific site or area. These storm lists were synthesized with the lists produced in the present study. The coarse lists from the previous studies were developed mainly from data searches similar to this study and scans of historical weather charts. In the Venture study, however, a storm severity index derived from Sable Island surface wind records was also given a considerable weight in the selection and ranking of candidate storms. A compiled storm list for each of the referenced studies is given in Appendix A. These storms and the associated sources were referenced in the final storm candidate list also given in Appendix A.

3.2.5 Long Term Hindcast Series

Storms were added to the candidate list using wave height thresholds in the SOWM and WES 20 year hindcast series. Three modes of entry were allowed. First, any of the 30 highest SOWM and WES storms in each region (SS,GB) listed in Brown et al. (1986) which were not already in the candidate list were added. Second, storms at the

SOWM grid point nearest Hibernia in which the hindcast significant wave height exceeded 30 feet were added if they did not appear in the list from previous sources. Finally, the SOWM series at grid point 263/2 (38.8°N, 65.1°W) was scanned to select potential storms on Georges Bank and approaches to the western Scotian shelf. A threshold peak storm H_s of 6 metres was used to add storms not already contained in the candidate list.

3.2.6 Georges Bank Literature Survey

Previous storm selection studies were not suitable for identifying storms on Georges Bank, because of the different spatial domain used. Therefore, searches were carried out of accounts of major individual New England storms in a number of sources including: journals of the American Meteorological Society (specifically Monthly Weather Review, Weatherwise); Mariner's Weather Log; the NOAA publication "Storm Data". East coast storms accompanied by coastal damage, heavy coastal rain or snow, wind damage, or maritime casualties were examined on the NMC Final Analysis Series and added to the Georges Bank (EB) storm list if they were found to be capable of generating extreme waves in the Georges Bank area. This was done by subjective assessment by a meteorologist. The tropical storm selection procedures and results are given in Section 3.6.

3.3 THRESHOLD ANALYSIS RANKING (TAR)

In recent hindcast studies carried out by Oceanweather, increased emphasis has been given to a method of objective ranking of historical storms based upon readily available properties of the surface pressure pattern of extratropical storms. In a proprietary study of the Hibernia storm population Szabo et al. (1989), it was shown that there is a high correlation between certain storm properties and maximum H_s in a storm at a site.

The following storm properties which are most highly correlated with peak H_s in the western North Atlantic were extracted from the microfilm maps: (1) minimum central pressure; (2) deepening rate; (3) maximum pressure gradient in the fetch zone of wave generation oriented such that waves generated therein affect the site of interest; and

(4) duration of maximum pressure gradient and a storm intensity parameter or a severity index made up of the product of the strength of the gradient and its duration; and (5) total pressure drop across the storm.

For the present study, the above parameters were defined as follows:

1) minimum central pressure (mb) within the domain 40° - 55°N, 40° - 70°W;

2) maximum deepening rate (mb/24 hours) - the maximum 24-hour pressure drop terminating at a 6-hour map time when the low center is within the above domain;

3) maximum pressure gradient (mb/60 n.mi. (1-degree lat.)) - this gradient is simply scaled off the isobaric analysis in the tightest zone of maximum pressure gradient around the low situated over one of the regions of interest;

4) duration of maximum pressure gradient - that is, the number of maps (x 6 hours) on which the pressure gradient over the basin affected is at least 75% as strong as the maximum noted under (3). The storm intensity parameter is calculated as the product of the square of the maximum pressure gradient and the duration divided by two.

5) total storm pressure gradient (mb) - the maximum total pressure difference between the low center and the adjacent high pressure system in the quadrant of the low in which the maximum pressure gradient (3) was scaled.

Given sufficient measured wave height data in storms, the correlations between measured wave height and the above parameters may be used to calibrate the ranking system in terms of parameter thresholds. The calibration consists simply of defining for each single parameter that threshold which is satisfied by all observed (or hindcast) storms in which H_s exceeds a specified wave threshold. The established thresholds then provide a basis of a scoring system which can be used to identify and rank storms based upon peak H_s generating potential. For example, if the properties of a candidate storm exceed the thresholds established for each screening parameter, it will be assigned a threshold analysis ranking (TAR) score of 5 (i.e. a score of 1 for each parameter described above).

While the proprietary study noted above included a calibration against Hibernia measured and hindcast data, a similar calibration for all regions of interest in this study would require a much larger data base of measured peak H_s than is currently available. Also, especially on the Scotian Shelf, much of the measured data were acquired in shallow water or sheltered exposure. Nevertheless, the guidance of previous studies was used to establish a basis for assignment of relative ranking to candidate storms in the Master Candidate List (MCL) in terms of TAR score without specification of the quantitative correlation of TAR scores and peak H_s.

The following thresholds were used to establish TAR scores separately in SS (including Georges Bank) and GB storms:

Parameter	Scotian Shelf	Grand Banks
1 - min. central pressure (mb)	≤980	≤967
2 - max. deepening rate (mb/24 hr.)	≥ 18	≥ 18
3 - max. pressure gradient (mb/deg. lat)	≥ 6	≥ 6
4 - storm intensity mb^2 hr/(deg. lat)^2	≥324	≥324
5 - total storm gradient (mb)	≥ 50	≥ 67

For storms between 1957 - 1969, inclusive, TAR scores were assigned by meteorologists working from microfilm files of the NOAA NMC Final Analysis Series surface maps. For storms between 1970 - 1986, the microfilm files of AWC surface charts were used. The final TAR values associated with each storm are given for all storms in the coarse list (Appendix A).

3.4 DEVELOPMENT OF MASTER CANDIDATE LIST (MCL)

The preliminary lists derived from the above screenings were synthesized into a single list. The final master candidate coarse storm list (MCL) contained 532 separate events. A complete listing is given in Appendix A (Table A-2). This table is the result of tedious rationalization of several previous versions of the MCL for the Grand Banks, Scotian Shelf, and Georges Bank. Storms were classified as either GB, SS, EB or combined events. For storms which affected both SS and GB regions, separate TAR scores were assigned for each region. Table A-2 also indicates different data sources utilized and the corresponding peak significant wave height (when available). As expected, there is a considerable overlap between the alternate source lists; however, there is also a surprising degree of non-overlap.

The following numbers of candidate storms were identified in each area:

- SS (covering EB)		240 storms
- EB not found in original SS list		19 "
- GB only		138 "
- SS, GB combined		135 "
	TOTAL	532 storms

3.4.1 An Independent Check of the MCL Using GWC

Following the establishment of the MCL, a data source which was not originally used in the storm searches was scanned. This source is the computer file of gridded geostrophic winds at 6-hourly intervals for the period 1946-1986 known as the AES Geostrophic Wind Climatology (GWC), Swail (1985). The source of pressure fields from which winds were calculated is the Fleet Numerical Oceanography Center (FNOC) of the U. S. Navy.

The GWC was scanned within the period of the MCL (Jan. 1, 1957-Dec. 31, 1986) for occurrences of geostrophic wind speed above selected thresholds. To identify possible storms in the GWC, two searches were referred to from several trial runs made. The first search identified all occurrences of geostrophic winds greater than or equal to 78 knots at grid points within the domain 40° to 50° North latitude, and 40° to 70° West longitude. A second search identified all occurrences of geostrophic winds greater than or equal to 60 knots (mainly for Georges Bank).

The search for possible storms in the above defined broad region yielded 407 individual occurrences ≥78 knots, which were easily grouped into 120 distinct events, all of which consisted of occurrences at grid points located in the broad area between Scotian Shelf and Grand Banks, including areas well offshore. Of the 120 events, 29 events could not be matched to storms in the MCL. A review of the data sources used to develop the MCL, for the GWC events, concluded that none of those events exceeded the threshold of storms in the MCL. Most events were easily rejected, as the GWC "event" actually consisted of a single occurrence at a single grid point. This occurred in 17 of the 29 GWC only events. In another 5 events, there was again only a single synoptic hour selected, but in this case at two adjacent grid points. Thus most of the events were minor storms, but during which the FNOC pressure fields had produced a localized, intense pressure gradient. None of the longer duration events were admitted, either because of intensity considerations, or because the specific areas of interest in this study were not significantly affected.

The search for possible storms in the Georges Bank area using the 60 knot geostrophic wind threshold (approximately 40 knots surface winds) yielded 220 individual occurrences, which were grouped into 110 distinct events. Of these, 26 events could not be matched with storms in the MCL. Again, it was found that 15 of the 26 events consisted of occurrences at a single synoptic hour and therefore severely duration limited. Of the remaining GWC Georges Bank events, only one was judged to be of sufficient intensity to be added to the Georges Bank population, namely the storm of 15-17 January, 1980. This was also of sufficient intensity to be selected as one of the 20 top-ranked Georges Bank storms, and is identified simply as a "new" storm in the refined storm lists.

3.5 REDUCTION OF MASTER CANDIDATE STORM LIST

Distillation of the MCL to the target level of 60 to 70 storms proceeded in basically three stages. First, the MCL was reduced in size by a factor of two by ranking the storms on the basis of the TAR assignments, and further study of the screening data available for each storm in the MCL (i.e. peak wind speed, duration, severity index; peak wave heights from ship observation, hindcast or buoy measurement, and METOC charts; storm summaries in previous studies, and TAR assignment). The second stage of refinement sought to select a population of storms consisting of the top 30 to 35 storms in each basin. It was expected that there would be sufficient overlap of storms in the region-stratified lists, such that the total population would consist of about 50 storms.

The selection of storms in the final target lists for each basin involved mainly the detailed study of the sequences of 6-hourly series of NOAA Final Analysis charts. These map sequences were reproduced in hard-copy from the microfilm file, to facilitate repeated reference to pressure patterns and individual ship reports. In effect, the maps were used to develop an estimate of the maximum wind speed and duration in each fetch zone capable of extreme wave generation within the regions of interest, to serve as a critical discriminant between otherwise comparable storms. This process involved estimation of specific kinematic properties of the storm wind field, without the actual specification of flow streamlines and isotachs, and therefore was carried out only by meteorologists skilled in kinematic analysis.

The target lists consisting of the top 35 storms in each basin are given in Table 3.2 for Georges Bank, Table 3.3 for Scotian Shelf, and Table 3.4 for Grand Banks. The overlap of storms between basins makes it difficult to provide lists of exactly 30 highest ranked storms in each basin. On the other hand, the overlap between basins was found to be much smaller than expected. Only 6 storms are common to Grand Banks and Scotian Shelf; there are 15 storms common to Scotian Shelf and Georges Bank. Only three storms are common to all three regions. As a result of this slight overlap, the combined list of these storms consisted of a total of 84 independent storms, as given in Table 3.5. The initial target population of 50 storms was then increased to a total of 68.

A third, and final, stage of refinement was carried out, producing the final population of 68 independent storms (represented in basin-stratified list) given in Table 3.6.

The list of the target storms as shown in Table 3.6, indicate the MCL reference number, start and end of the hindcast period for each storm, and the designated region which is affected by each storm. As shown a total of 33, 31 and 25 storms were assigned to the Grand Banks, Scotian Shelf, and Georges Bank, respectively.

TABLE 3.2 GEORGES BANK STORM LIST

Storm #	Area	Date of Storm Peak[1]	Overlap SS	Overlap GB	Remarks
68	SS	601217			not hindcast
95	SS	620308	*		
102	SS	621116			
106	SS	621231	*		
124	SS,GB	631220,631220	*		
147	SS	641202			
157	SS	650226			not hindcast
172	SS,GB	660129,660130	*		
184	SS	661225			not hindcast
189	SS,GB	670222,670222	*	$	
190	SS,GB	670224,670224			not hindcast
215	SS	690210	*		
223	SS	691227	*		
233	SS	701218			not hindcast
241	SS	710305			
282	SS,GB	721217,721218			
303	SS	730323			not hindcast
310	SS	731102			
372	SS	760203			
377	SS,GB	760316-760318	*	$	
384	SS,GB	761107,761107	*		
392	SS	770111			not hindcast
404	SS	780110			
416	SS,GB	781217,781219			not hindcast
421	SS	790206			
NEW	EB	800116			
443	SS	801122	*		
453	SS	810317	*		
462	SS	811126			not hindcast
463	EB,SS	811207,811207			
464	SS,GB	811217,811218	*		
493	SS	831026	*		
506	SS	840330	*		
512	SS,GB	850106,850107	*	$	
529	EB	860127			not hindcast
35			15	3	

* Indicates storm overlaps Scotian Shelf

$ Indicates storm overlaps Grand Bank

[1] Dates are in Year, Month, Day (e.g. 601217)

TABLE 3.3 SCOTIAN SHELF STORM LIST

Storm #	Area	Date of Storm Peak	Overlap		Remarks
			EB	GB	
28	SS	580402			not hindcast
95	SS	620308	*		
106	SS	621231	*		
124	SS,GB	631220,631220	*		
172	SS,GB	660129,660130	*		
189	SS,GB	670222,670222	*	$	
195	SS	670428			
215	SS	690210	*		
223	SS	691227	*		
226	SS,GB	700122,700123			
235	SS,GB	701227,701227			
260	SS,GB	720219,720220			
265	SS,GB	720327,720330			
325	SS,GB	740205,740207			
326	SS	740218			
339	SS	741020			not hindcast
377	SS,GB	760316,760318	*	$	
384	SS,GB	761107,761107	*		
386	SS	761119			
429	SS	791218			not hindcast
433	SS,GB	800208,800209			
443	SS	801122	*		
451	SS	810307			
453	SS	810317	*		
464	SS,GB	811217,811218	*		
467	SS,GB	820116,820117		$	
474	SS,GB	820214,820215		$	
487	SS,GB	830213,830214			
493	SS	831026	*		
495	SS,GB	831126,831128		$	
502	SS	840201			
506	SS	840330	*		
512	SS,GB	850106,850107	*	$	
527	SS	860107			not hindcast
NEW	SS	880309	–	-	Bonnie Lou II
TOTAL 35			15	6	

* Indicates storm overlaps Georges Bank
$ Indicates storm overlaps Grand Banks

NOTE: the Bonnie Lou storm was included for hindcast as requested by the Scientific Authority. Although it was severe, it was not necessarily one of the top 30.

TABLE 3.4 GRAND BANK STORM LIST

	Storm #	Area	Date of Storm Peak	Overlap SS	Overlap EB	Remarks
	40	SS,GB	590207,590208			
	41	SS,GB	590216,590217			not hindcast
	54	SS,GB	600109,600110			
	70	SS,GB	610121,610122			
	85	SS,GB	611215,611217			
	121	GB	631116			
	129	SS,GB	640114,640116			
	132	SS,GB	640209,640210			
	140	SS,GB	640316,640318			
	151	GB	650124			
	169	SS,GB	660109,660110			
	174	SS,GB	660214,660216			
	189	SS,GB	670222,670222	*	$	
	200	SS,GB	680105,680106			
	236	SS,GB	710106,710107			not hindcast
	237	SS,GB	710116,710118			
	309	SS,GB	731027,731028			
	317	GB	740104			
	329	SS,GB	740311,740312			
	377	SS,GB	760317,760318	*	$	
	394	GB	770321			
	395	SS,GB	770207,770207			
	408	GB	780304			
	434	SS,GB	800211,800212			
	442	SS,GB	801119,801120			
	465	SS,GB	811230,820131			
	467	SS,GB	820116,820117	*		
	474	SS,GB	820214,820215	*		Ocean Ranger Storm
	488	SS,GB	830216,830217			
	495	SS,GB	831126,831128	*		
	499	GB	831220			
	512	SS,GB	850106,850107	*	$	
	515	SS,GB	850128,850129			
	523	GB	851216			
	526	GB	860105			
TOTAL	35			6	3	

TABLE 3.5 COMBINED EB, SS & GB TOP-RANKED STORM LIST

Storm #	Area	Storm Peak
28	SS	580402
40	SS,GB	590207,590208
41	SS,GB	590216,590217
54	SS,GB	600109,600110
68	SS	601217
70	SS,GB	610121,610122
85	SS,GB	611215,611217
95	SS	620308
102	SS	621116
106	SS	621231
121	GB	631116
124	SS,GB	631220,631220
129	SS,GB	640114,640116
132	SS,GB	640209,640210
140	SS,GB	640316,640318
147	SS	641202
151	GB	650124
157	SS	650226
169	SS,GB	660109,660110
172	SS,GB	660129,660130
174	SS,GB	660214,660216
184	SS	661225
189	SS,GB	670222,670222
190	SS,GB	670224,670224
195	SS	670428
200	SS,GB	680105,680106
215	SS	690210
223	SS	691227
226	SS,GB	700122,700123
233	SS	701218
235	SS,GB	701227,701227
236	SS,GB	710106,710107
237	SS,GB	710116,710118
241	SS	710305
260	SS,GB	720219,720220
265	SS,GB	720327,720330
282	SS,GB	721217,721218
303	SS	730323
309	SS,GB	731027,731028
310	SS	731102
317	GB	740104
325	SS,GB	740205,740207
326	SS	740218
329	SS,GB	740311,740312
339	SS	741020
372	SS	760203
377	SS,GB	760317,760318
384	SS,GB	761107,761107
386	SS	761119
392	SS	770111
394	GB	770121
395	SS,GB	770207,770207
404	SS	780110
408	GB	780304
416	SS,GB	781217,781219
421	SS	790206
429	SS	791218
NEW	EB	800116
433	SS,GB	800208,800209
434	SS,GB	800211,800212
442	SS,GB	801119,801120
443	SS	801122
451	SS	810307
453	SS	810317
462	SS	811126
463	EB,SS	811207,811207
464	SS,GB	811217,811218
465	SS,GB	811230,811231
467	SS,GB	820116,820117
474	SS,GB	820214,820215
487	SS,GB	830213,830214
488	SS,GB	830216,830217
493	SS	831026
495	SS,GB	831126,831128
499	GB	831220
502	SS	840201
506	SS	840330
512	SS,GB	850106,850107
515	SS,GB	850128,850129
523	GB	851216
526	GB	860105
527	SS	860107
529	EB	860127
NEW	SS	880309

TABLE 3.6 FINAL LIST OF TOP 68 STORMS

Storm MCL #	Storm Period Start End	GB	SS	EB
40	59020612-59021012	*		
54	60010900-60011300	*		
70	61011912-61012312	*		
85	61121412-61121912	*		
95	62030600-62030912		*	*
102	62111412-62111912			*
106	62123000-63010218		*	*
121	63111400-63111818	*		
124	63121900-63122118		*	*
129	64011212-64011718	*		
132	64020800-64021018	*		
140	64031512-64031912	*		
147	64113000-64120312			*
151	65012112-65012512	*		
169	66010812-66011212	*		
172	66012612-66013012		*	*
174	66021318-66021812	*		
189	67022100-67022500	*	*	*
195	67042700-67050200		*	
200	68010418-68010800	*		
215	69020900-69021218		*	*
223	69122600-69123012		*	*
226	70012000-70012400		*	
235	70122600-70123000		*	
237	71011518-71011918	*		
241	71030300-71030700			*
260	72021812-72022200		*	
265	72032612-72033100		*	
282	72121512-72121912			*
303	73032112-73032500			*
309	73102600-73102912	*		
310	73110100-73110512			*
317	74010200-74010700	*		
325	74020400-74020800		*	
326	74021612-74022000		*	
329	74031012-74031412	*		
377	76031600-76032000	*	*	*
384	76110512-76111000		*	*
386	76111812-76112300		*	
394	77011900-77012300	*		
395	77020512-77021012	*		
404	78010812-78011212			*
408	78030100-78030500	*		
421	79020300-79020712			*
NEW	80011412-80011812			*

TABLE 3.6 LIST OF FINAL TOP 68 STORMS (cont'd)

Storm	Storm Period			
MCL #	Start End	GB	SS	EB
433	80020612-80021012		*	
434	80021000-80021400	*		
442	80111812-80112212	*		
443	80112106-80112418		*	*
451	81030500-81031000		*	
453	81031512-81032000		*	*
463	81120412-81120812			*
464	81121500-81121912		*	*
465	81122912-82010300	*		
467	82011300-82011900	*	*	
474	82021200-82021600	*	*	
487	83021000-83021500		*	
488	83021506-83021900	*		
493	83102400-83102800		*	*
495	83112400-83113012	*	*	
499	83121900-83122400	*		
502	84012912-84020312		*	
506	84032812-84040112		*	*
512	85010400-85010900	*	*	*
515	85012512-85013012	*		
523	85121512-85122112	*		
526	86010212-86010612	*		
NEW	88030700-88031012		*	
68		33	31	25

3.6 GEORGES BANK TROPICAL STORM SELECTION

The objective of this task was to develop a ranked list of about 30 of the most severe historical tropical cyclones to affect Georges Bank.

Many tropical cyclones which cross Georges Bank, especially late in the hurricane season, are undergoing transformation to extratropical cyclones, and the population of extratropical cyclones identified in this study includes some cyclones of tropical origin. However, an attempt was made to develop a separate list of cyclones of tropical origin which have retained tropical characteristics to a significant degree upon crossing Georges Bank, since these storms will ultimately require wind field modelling techniques quite different from those used for the extratropical storms and possibly finer wind and wave model grids.

Since tropical cyclones in Georges Bank are much less frequent than extratropical cyclones, populations are developed for two historical periods: (1) 1938 - 1956; (2) 1957 - 1987. The early period allows capture of the great east coast storms of 1938 and 1944 and the early 1950's, while the tracks and properties of storms in the latter period, which overlaps the period in which extratropical storms were selected, are probably better known.

In addition to the data sources referred to in the storm selection regarding extratropical storms, the following sources particular to tropical cyclones were also referred to:

1. the compilation of storm tracks, Neumann et al. (1978),"Tropical Cyclones of the North Atlantic Ocean 1871 - 1986," National Climatic Data Center, Asheville, NC, Historical Climatology Series 6-2, September 1987;
2. the comprehensive tape file of North Atlantic tropical cyclones known as HURDAT, maintained by the NOAA National Hurricane Center, Miami, FL;
3. annual summaries of North Atlantic hurricanes published in the Monthly Weather Review;
4. storm reports on major individual storms published by the NOAA National Hurricane Center;

5. Barks, E.A. and W.G. Richards (1986), "The Climatology of Tropical Cyclones in Atlantic Canada," AES, Atlantic Region Report # MAES 4-86.

The results of this search are provided in the form of:

1. date ordered lists of candidate tropical cyclones for each historical period, which include preliminary estimates of storm intensity time and rank-ordered lists of selected tropical cyclones, including preliminary estimates of storm parameters: central pressure, storm pressure anomaly, radius of maximum wind, forward speed, maximum wind speed, and peak significant wave height;
2. computer-plotted tracks of storms selected.

3.6.1 Candidate Storm Population

The work of identifying candidate tropical storms in Georges Bank is considerably easier than that of identifying extratropical storms, since it can be safely assumed that all tropical cyclones which have affected the region are already included in one or more of the previous studies cited above. Therefore, it was not necessary to scan raw data sources or archived weather maps in order to identify candidate storms. However, reference to these sources was still required for the refinement and ranking of the lists of candidate events.

The first step was to identify all storms in the assembled data bounded by 40°N - 42.5°N latitude, 65°W - 75°W longitude. This region encompasses all of the Georges Bank study area and extends far enough outside the region to capture all storms which could possibly have generated extreme sea states on Georges Bank itself. The search region purposely extends farther west of Georges Bank than east, since Georges Bank is on the strong side of storms which pass west of Georges Bank, perhaps even as far west as Long Island.

The separate lists of candidate storms developed for each historical period are given in Appendix B. In addition to storm dates, these lists include: storm class as defined in Neumann et al. (1978); (2) the date of closest approach of the cyclone center to EB; (3) estimated minimum central pressure on EB; (4) forward velocity; (5) estimated maximum wind at EB; (6) estimates of cyclone minimum central pressure, forward velocity, and maximum wind south of EB, given as the storm center crosses 35°N latitude.

The candidate population consist of 27 storms in the 19-year period 1938 to 1956 (Table B-1), and 41 storms in the 30-year period 1957 - 1986 (Table B-2). Average storm frequency is somewhat greater in the earlier period, and especially in the early 1950's, a property of Atlantic east coast cyclone frequency which has been noted and discussed in previous studies.

3.6.2 Refinement of Candidate Lists

Storms in the candidate lists include many storms which are classified as fully transformed to extratropical status or in the process of undergoing such transformation. Part of the process of refinement of the candidate populations was the assessment of the degree of transformation from all available data sources, and the deletion of all storms which should be considered as essentially extratropical in nature. Most of the candidates deleted were considered to be extratropical. Most of those deleted storms were also of weak to moderate intensity, indicating that east coast hurricanes tend not to become intense extratropical storms in the Georges Bank region. Note also that in the list of candidate storms in the recent period, which overlaps the extratropical storms hindcast period, only two candidates (storms 14 and 28 in Table B-1) appear also in the Georges Bank extratropical storm population (Appendix A).

After deletion of extratropical storms, the candidate lists were further refined by deletion of weaker tropical cyclones. The most significant ranking parameter for this purpose is considered to be minimum central pressure. In general, tropical cyclones with central pressures of about 990 mb or less were retained.

The refined list of tropical cyclones is given in Appendix B, Table B-3. This list includes 15 storms from the early historical period, and 18 storms from the recent historical period.

The ranking of storms in the refined list required more detailed study of raw data sources for each storm, including individual storm reports and compilations of available aircraft reconnaissance data. For each storm, estimates were developed of the storm parameters required to drive the ODGP cyclone wind model. These parameters are given in Table B-3 and include: minimum central pressure (P_o); peripheral storm pressure(P_t); radius of maximum wind (Rmax); forward velocity (V_f). These parameters were then used to drive a simplified parametric wind model, which is based upon the full ODGP cyclone model (Cardone et al., 1976). This parametric model provides an estimate of the maximum surface wind, which in turn was used to drive a simplified parametric version of the ODGP cyclone wave hindcast model (unpublished) to estimate maximum significant wave height.

Separate ranked lists of tropical cyclones for each historical period are given in Tables 3.7 and 3.8. These tables also include the estimated maximum wind and maximum significant wave height in Georges Bank for each storm. It should be noted that these numbers are crude estimates for storm ranking purposes only, the actual hindcast values can be found in Table 6-2.

Computer-plotted tracks are given in Figure 3.1 for each selected cyclone. Tracks are based upon 6-hourly positions contained in NOAA sources.

TABLE 3.7

SELECTED HIGH RANKED TROPICAL CYCLONES AT GEORGES BANK

1938 - 1956

#	YYMM	DD - DD	NAME	DATE OF C.A.	Po	Pf	Rmax	Vf	[1]Vmax	[1]H_s
14	5409	02 - 14	EDNA	11/18Z	947	1018	18	29	53.42	13.36
4	4409	09 - 16	-	15/03Z	957	1029	33	28	52.63	13.16
13	5408	25 - 31	CAROL	31/15Z	967	1014	24	30	46.25	11.56
1	3809	10 - 22	-	21/21Z	954	1010	35	20	43.88	10.97
10	5308	11 - 16	BARBARA	15/12Z	967	1013	23	19	40.54	10.13
7	5008	11 - 22	ABLE	21/03Z	967	1014	33*	19	40.49	10.12
2	4008	30 - 03	-	03/12Z	972	1016	33*	21	40.42	10.11
11	5308	28 - 09	CAROL	07/15Z	972	1016	33*	20	39.93	9.98
3	4009	10 - 19	-	16/18Z	972	1016	33*	20	39.93	9.98
9	5202	02 - 04	-	04/18Z	987	1011	33*	33	38.11	9.53
6	4609	12 - 17	-	15/06Z	875	1013	33*	19	37.22	9.31
15	5608	09 - 19	BETSY	18/00Z	975	1015	47	18	36.94	9.24
2	5310	03 - 10	-	07/15Z	978	1015	33*	18	36.94	9.09
8	5008	30 - 16	DOG	12/12Z	978	1016	50	18	36.07	9.02
5	4506	20 - 01	-	27/15Z	983	1017	33*	13	32.70	8.17

YYMM - year, month of storm
DD - DD - beginning and ending day of storm
DATE of C.A. - date of closest approach
Po - central pressure
Pf - peripheral pressure
Rmax - radius of maximum wind (n.m.)
* - average Rmax
Vf - forward storm velocity (knots)
Vmax - maximum wind speed (metres/second)
H_s - significant wave height (metres)

[1] estimates for storm ranking purposes only - hindcast results in Table 6-2.

TABLE 3.8

SELECTED HIGH RANKED TROPICAL CYCLONES AT GEORGES BANK

1957 - 1986

#	YYMM	DD - DD	NAME	DATE OF C.A.	Po	Pf	Rmax	Vf	[1]Vmax	[1]H_s
19	6008	29 - 13	DONNA	12/21Z	967	1014	48	36	48.26	12.06
24	6310	16 - 30	GINNY	29/12Z	958	1014	18	25	47.00	11.75
27	6810	13 - 21	GLADYS	21/06Z	975	1015	30	34	45.47	11.37
18	6008	13 - 21	CLEO	20/09Z	967	1017	13	24	44.75	11.19
28	6909	05 - 10	GERDA	09/20Z	979	1016	30	37	42.36	10.59
33	8508	16 - 01	GLORIA	27/18Z	986	1013	35*	35	40.42	10.11
25	6408	31 - 15	DORA	14/21Z	983	1014	33*	30	39.80	9.95
32	7608	06 - 10	BELLE	10/06Z	983	1018	18	23	38.60	9.65
23	6209	29 - 08	DAISY	07/09Z	978	1013	33*	24	38.50	9.63
22	6110	15 - 22	GERDA	20/18Z	978	1015	33*	21	37.82	9.45
21	6109	30 - 09	FRANCES	08/18Z	972	1018	14	11	36.96	9.24
29	7108	10 - 17	BETH	15/18Z	977	1018	48	16	36.29	9.07
31	7507	23 - 28	BLANCHE	28/06Z	980	1014	30	18	35.27	8.82
30	7206	14 - 22	AGNES	22/18Z	980	1015	33*	17	35.06	8.77
17	5907	05 - 12	CINDY	11/12Z	987	1016	33*	21	34.52	8.63
16	5808	24 - 31	DAISY	29/18Z	982	1013	50	18	33.24	8.31
26	6409	13 - 24	GLADYS	24/06	982	1010	20	16	32.12	8.03
20	6109	11 - 26	ESTER	22/12Z	990	1016	50	9	26.60	6.65

YYMM - year, month of storm
DD - DD - beginning and ending day of storm
DATE of C.A.- date of closest approach
Po - central pressure
PF - peripheral pressure
Rmax - radius of maximum wind (n.m.)
* - average Rmax
Vf - forward storm velocity (knots)
Vmax - maximum wind speed (meters/second)
H_s - significant wave height (meters)

[1] estimates for storm ranking purposes only - hindcast results in Table 6-2.

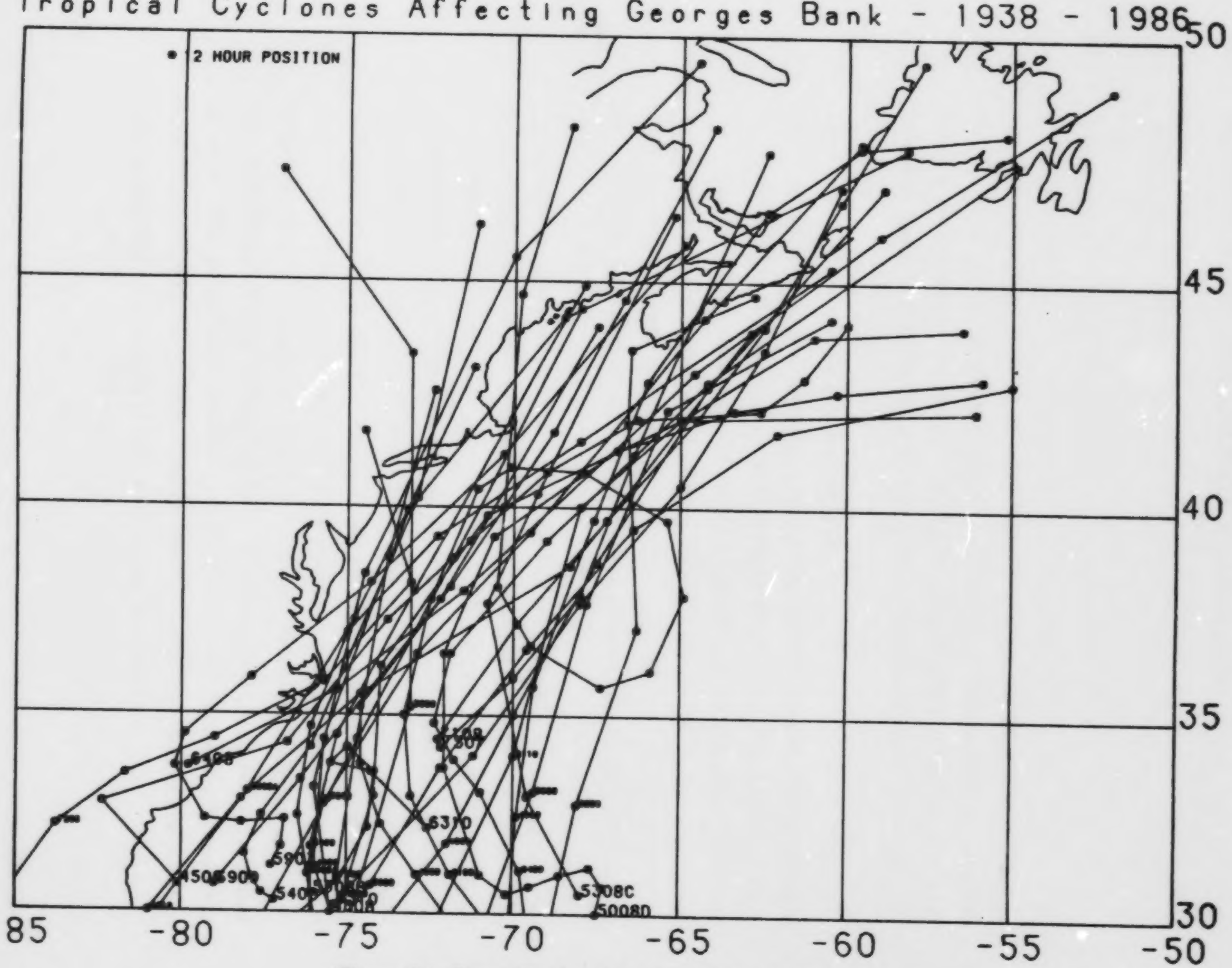


Figure 3.1 Storm Tracks of Tropical Cyclones Affecting Georges Bank

4.0 WIND FIELD ANALYSIS AND WAVE HINDCASTING

4.1 WIND FIELD ANALYSIS

4.1.1 Approach

The method used for hindcasting wind fields for the selected 68 storms is based on Cardone et al. (1980). It is based on man-machine mix intensive wind field analysis using a blend of surface pressure analysis using Cardone's Marine Planetary Boundary Layer (MPBL) Model and kinematic analysis wind fields.

The hindcast period of each storm consists of:

(a) period of spinup of background seas in the model domain in which principal wave generation occurs prior to the peak of the selected storm (about 48 hrs.);

(b) period during which selected storm generates seas in the study areas and including always the period within ± 12 hours of expected occurrence of peak sea states in each area; and

(c) 24-hour period following (b) in which peak seas continue to decay.

For the spinup and decay periods, the approach is to specify winds from the sea level pressure analyses. Gridded pressures are then converted to "effective neutral" 20-m winds through the marine planetary boundary layer (MPBL) model developed by Cardone (1969, 1978). The "effective neutral" wind speed, introduced by Cardone (1969) to describe the effects of thermal stratification in the marine boundary layer on wave generation, is simply the wind which would produce the same surface stress at the sea surface in a neutrally stratified boundary layer as the wind speed in a boundary layer of a given stratification. This is consistent with the similarity approach and produces analogous functions. The baroclinic forcing term is supplied at each grid point from climatological horizontal air temperature gradients appropriate to the North Atlantic Ocean in the cold season. The atmospheric stability term is specified as a function of local geostrophic wind direction.

Kinematic winds are extracted from the streamline/isotach analyses at the fine mesh grid point locations for the period (b), the peak of the storm, and represent the effective 1-hour average 20-m level neutral wind. Reports of wind speed from ships and rigs equipped with anemometers are transformed into the effective neutral 20 m values. For ships which use estimated wind speeds, values are adjusted according to the Scientific Beaufort scale. The kinematic winds replace the winds derived from the pressure field in the interior of the kinematic domain, and are blended with the pressure-derived winds along the boundaries of the domain.

Kinematic winds are by far the most accurate and least biased winds, primarily because the method allows a thorough re-analysis of the evolution of the wind fields. Kinematic analysis also allows the wind fields to represent effects not well modelled by pressure-wind transformation techniques, such as inertial accelerations associated with large spatial and temporal variations in surface pressure gradients and deformation in surface winds near and downstream of coasts.

The final step in the wind field analysis is interpolation from 6 hours to 2 hours (as required to drive the wave model). Linear interpolation in time of zonal and meridional wind components is used for wind direction, while the fourth power of wind speed is used for interpolation of wind speed. Further interpolation is done near centres of rapidly propagating cyclones to avoid errors due to excessive smoothing of winds. The gridded wind fields were produced on the ODGP wave model grid shown in Figure 4.1.

4.1.2 Grid Specifications

The model domain and grid specification used for the wind and wave hindcasts are shown below (see Figure 4.1). The model is comprised of two nested grids, coarse grid and fine grid, as follows:

	Coarse Grid	Fine Grid
domain:	25°N - 67.5°N	38.75°N to 53.75°N
	20°W - 80°W	42.5°W to the coast
spacing:	1.25°lat x 2.5°long	0.625°lat x 1.25°long
active grid points:	662	333
time step:	2 hours	2 hours

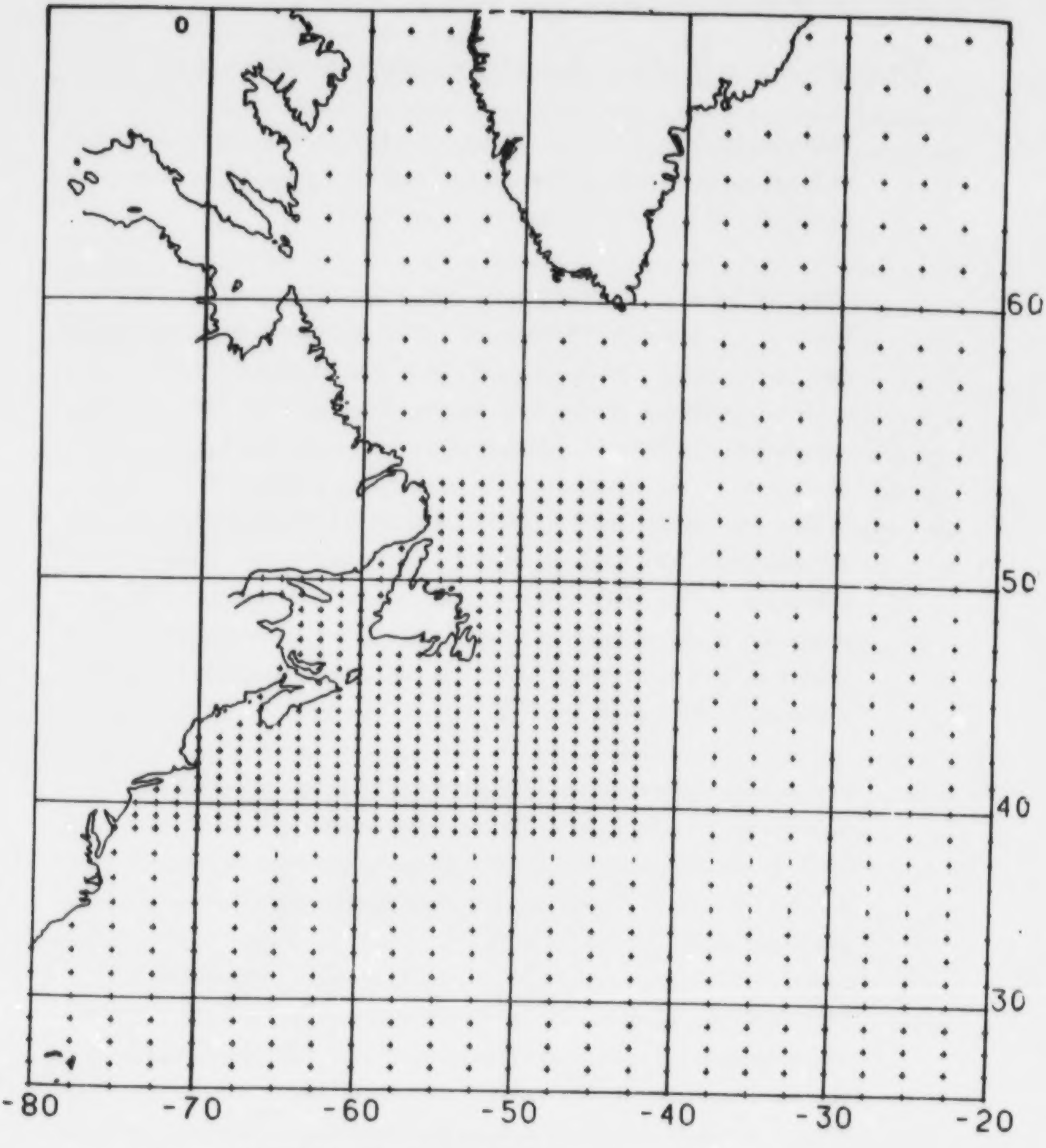


Figure 4.1 - The ODGP Wind/Wave Model Grid

4.1.3 Method and Procedures

The general steps involved in producing the wind fields are outlined below.

1. Define the hindcast duration for each storm which consists of three subperiods as described in previous section: (a) 24 - 48 h spin-up period, (b) storm peak period (24 - 48 h), and (c) 24-h storm decay period.

2. Select the historical chart series, for each storm, which is most complete in terms of data coverage and which appears to provide the best initial guess specification of the time evolution of the relevant synoptic features. On a suitable overlay to the selected chart series, plot all additional spot observations assembled for this storm.

   In the present study the NOAA/NMC Northern Hemisphere surface pressure analysis charts were used as base maps for the reanalysis. These 6-hourly charts, produced on a polar stereographic projection at scale 1:1,000,000, were obtained from microfilm copies. Additional observations were plotted on an overlay at same scale (the COADS data obtained from AES were used for storms up to 1979 period, and NMC TDF11 tapes for more recent storms).

3. For period (a) perform a gross check on continuity and consistency of successive 6-hourly pressure fields, correct gross departures from continuity and gross errors in pressure gradients. Digitize the pressure fields and compute the 6-hourly wind fields for this spinup period. Winds are computed directly at wave model grid points through the MPBL.

4. For period (b) construct a detailed continuity chart of major features (cyclone and anticyclone centres, frontal axes, wind maxima). Plotted ship wind observations are corrected for stability, anemometer height, and Beaufort scale. Winds from coastal and island stations are transformed to effective over-water exposure.

5. Carry out a detailed reanalysis of the 6-hourly pressure field, with pressure fields reanalysed as necessary to impose consistency between wind and pressure fields. This step is applied basically to a sufficient domain of period (b) fields to cover the storm region of interest. It is also applied to the domain of the model fine grid. Compute winds directly at coarse and fine model grid points through the MPBL (using PRESTO WIND Program).

6. For the 24- to 36-hour period centred on the occurrence of peak winds in the study areas, carry out a kinematic analysis over the domain of the fine grid in terms of streamlines and isotachs at 6-hourly intervals. The kinematic analyses were drawn on special map overlays (computer-plotted) which display the wind fields specified at step 5 on the fine grid, the ship or rig (if available) reports of wind referenced to effective-neutral 20-m height, and effective over-water winds transformed from winds measured at island and coastal stations within the domain of the fine grid. The kinematic analysis is carried out completely by hand by a skilled synoptician. Streamlines and isotachs are digitized in terms of wind speeds and directions directly on the fine-mesh grid. Inside the boundary of the fine grid, kinematic winds override MPBL winds (using subprogram KINEMA).

7. Display the entire sequence of 6-hourly blended wind fields on the coarse and fine grids as wind barbs or vectors, and display the time history of modelled winds at a number of locations in each area where measurements are available, with measured winds superimposed if available. Edit the field to correct any errors or inconsistencies.

The step-by-step procedure given above incorporates a number of standard objective components of Oceanweather's wind analysis systems, see Cardone (1978) and Cardone et al. (1980).

4.2 WAVE HINDCASTING

The ODGP model was used to hindcast the wave fields for the selected storms. The ODGP wave model is a deep-water, fully directional spectral model (24 directions by 15 frequencies). It evolved from the Spectral Ocean Wave Model (SOWM) of the U.S. Navy. This model incorporates a relatively simple representation of the source terms in the spectral energy balance equation compared to more recent formulations. The calibration of these parameterizations has remained stable over the past many years, unlike most contemporary models, which appear to undergo continuous tuning. The ODGP model has been used in hindcast studies of extreme wave regimes of many different types (e.g. winter cyclones, typhoons, hurricanes, and monsoons). The model, when driven by wind fields of accuracy about ± 2 m/s in speed, ± 20 ° in direction, provided unbiased specifications of significant wave height and peak frequency with a scatter index of about 10%, which, incidentally, is comparable to the scatter in estimates of these quantities from measured 20-minute wave records. The model exhibits conspicuous skill in the specification of the complicated directional mix of local sea, and propagation swell excited by the moving quasi-circular wind fields of migratory extratropical and tropical storms. A detailed description of the model physics, numerical algorithms and model evaluation is given in Cardone et al. (1976), Reece and Cardone (1982), MacLaren Plansearch Limited (1985), MacLaren Plansearch and Oceanweather (1985, 1985a), and Eid et al. (1989).

4.2.1 Wave Model Grid Specification

The model domain and grid specification are shown in Figure 4.1, and described in the previous section. The 2-D spectrum is resolved into 24 directions (15° bandwidth) and 15 frequency bands as shown in Table 4.1.

TABLE 4.1

The 15 ODGP Frequency Bands

Band	Nominal Frequency (Hz)		Bandwidth (Hz)
1	14/180	=0.03889	1/180
2	16/360	0.04444	1/180
3	18/360	0.05000	1/180
4	20/360	0.05556	1/180
5	22/360	0.06111	1/180
6	24/360	0.06667	1/180
7	26/360	0.07222	1/180
8	29/360	0.08056	1/ 90
9	33/360	0.09167	1/ 90
10	37/360	0.10278	1/ 90
11	42/360	0.11667	1/ 60
12	48/360	0.13333	1/ 60
13	57/360	0.15833	1/ 30
14	75/360	0.20833	1/ 15
15	111/360	0.30833	2/ 15

4.2.2 Physics Algorithms

Only a brief summary is presented here. For detailed description of the model physical and numerical algorithms, the reader is referred to Cardone et al. (1976) and MacLaren Plansearch Limited (1985). The general energy balance equation for wave evolution is given by the equation:

$$\frac{\partial S}{\partial t}(f,\theta;x,t) + Cg.\ \nabla\ S = F(f,\theta;x,t)$$

Where:

$S=S(f,\theta;x,t)$	is the two-dimensional wave spectrum as a function of frequency (f) and direction (θ) at a given location (x) and time (t);
$C_g=C_g\ (f,\theta)$	is the deep-water group velocity;
$F(f,\theta;x,t)$	is the source function which represents all physical processes that transfer energy from or to the spectrum.

The source function may be expressed as a sum of three terms:

$$F = F_{in} + F_{nl} + F_{ds}$$

Where:
F_{in} = energy input function by wind,
F_{nl} = non-linear transfer by wave-wave interaction,
F_{ds} = energy dissipation term.

The input source function (F_{in}) is represented by ODGP as a function of wind speed and frequency according to the linear equation:

$$F_{in} = A + B \times S$$

The A term in the above equation = A (f,u) is a function of frequency (f) and wind speed (u). This term represents Phillips' external turbulent pressure forcing. The B.S. term corresponds to Miles' linear feedback mechanism. The term B(f,u.) is expressed in ODGP as a function of frequency and the friction velocity (u.).

The energy transfer associated with the non-linear wave-wave interaction is not explicitly included in ODGP.

The propagation scheme used in the ODGP was constructed for use with a spherical earth, and combines elements of jump and interpolatory propagation. When an ocean basin is mapped on a plane by an arbitrary projection, and a rectangular or triangular grid overlaid, the distance from each point to its neighbours, and thus the coefficients in the propagation formula, are functions of both latitude and longitude. Coefficients dependent on latitude alone arise when one set of grid lines is meridians equally spaced, and the other set parallels at any convenient spacing.

The ODGP growth algorithm developed by Cardone, Pierson, and Ward (1976), is a part of the family of PTB discrete-type spectral models described by Pierson, Tick, and Baer (1966). While the ODGP spectral growth/dissipation algorithm is of the PTB type, significant differences between it and the U.S. Navy SOWM model (also a PTB type) evolved in the application and verification of the ODGP model against measured wave spectra in hurricanes. An important difference is in the calculation of the wave growth as a function of the angle between the wave direction and wind direction. In the SOWM, the energy in a given frequency component summed within ±90 degrees of the local wind is the quantity subjected to growth. The incremental growth is then spread out over the same components.

In the ODGP model, each downwind spectral component is grown separately, and after computation of growth for all components within ±90 degrees of the local wind direction, energy is redistributed over directional sectors. This algorithm leads to slower growth of wave height with time in a turning wind than in a wind of constant direction.

4.2.3 Source-Term Algorithm

Two variants of the spectral growth/dissipation algorithm were tested in this study.

ODGP. This algorithm is implemented in the wave model as a subroutine called CMPE24. While a few changes in the code and numerics of this subroutine have been effected since the original version was developed in the ODGP-Analysis Phase (ODGP-AP), the calibration of this spectral growth/dissipation algorithm and the quantitative behaviour of hindcasts of tropical and extratropical cyclones have not changed. The algorithm is described in most detail in the original ODGP-AP report (proprietary to ODGP-AP participants) and most recently in the public domain in MacLaren Plansearch Limited (1985).

ODGP2. A slightly modified version of the ODGP spectral/growth algorithm was developed in 1983, and has been used experimentally since then. The subroutine which implements the modified algorithm is called CMPE27. The changes affect only the behaviour of the high-frequency part of the wave spectrum, and were made in order to make the so-called saturation range of the spectrum more responsive to the stage of wave development.

CMPE27 differs from CMPE24 in three particulars:

1. The integrated band (0.24167 hz to 3.0 hz) is not automatically saturated by the local wind, but is subject to grow, propagate, and dissipate.

2. The f^{-4} range is not used.

3. Phillips "constant" α is allowed to float as a function of sea state, specifically, $\alpha = 0.0081(E_{sat}/E)^{0.23}$

where E is the non-dimensional total variance and E_{sat} is the fully-developed value of same.

The two models (CMPE24 and CMPE27) were run for all storms to check the effect of the above modifications on model results. However the final hindcast results used in this study are those from CMPE27.

4.2.4 TMA Scaling of Hindcast Spectra

The ODGP model as applied in this study uses deep water representations of the physical mechanisms modelled in the source terms, and a deep water propagation scheme. Interestingly, the ODGP as originally applied in the Ocean Data Gathering Program study in the early 1970's, also included shallow water effects associated with refraction and shoaling (handled in the propagation step). In the source term treatment, only a weak viscous bottom-friction mechanism was added. As a result, the model exhibited what is now believed to be weaker attenuation of wind-driven sea states in shallow water than observed.

Recent shallow water wave models have emphasized the importance of the roles of non-linear wave-wave interactions (which are considerably enhanced in shallow water), and turbulent bottom friction mechanisms, which in general provide much greater attenuation of surface wave energy than viscous models. A number of second and third generation wave models employing these new mechanisms have been introduced, but evidently the properties of these models vary greatly and their quantitative behaviour in hindcasts of real events suggest caution in the application of any particular model at this time. Intercomparison of shallow water models in programs like SWIM and SHIP may provide guidance in this matter.

One of the seeming empirical consequences of the source term balance in shallow water wind-driven seas is the recent finding that wind-wave spectra in shallow water often follow a self-similar form that can be described by the so-called TMA spectrum (Bouws et al., 1985).

$$S_{TMA}(f,h) = S_J(f)\,\phi\,(\omega_h)$$

where S_J is the JONSWAP spectrum (Hasselmann et al. 1973) and

$$\phi(\omega_h) = \frac{k^{-3}(\omega,h)\,\frac{\partial k}{\partial \omega}(\omega,h)}{k^{-3}(\omega,\infty)\,\frac{\partial k}{\partial \omega}(\omega,\infty)}$$

where ω is radian wave frequency, k is wave number, h is water depth and

$$\omega_h = 2\,\pi\,f(h/g)^{1/2}$$

ϕ is Kitaigorodskii et al. (1975) factor which translates a deep water equilibrium range relation to an intermediate or shallow depth form.

A systematic tendency was found for deep-water hindcast sea-states at a number of measuring sites in the study area to run higher than measurements. This might be due to the neglect of shallow water processes in the hindcast model. To test this, the "TMA" scaling was applied by transforming the hindcast deep water spectra to shallow water through the application of the Kitaigorodskii factor to the whole of the hindcast spectrum. The main objective of this exercise was to help assessing the degree to which sea states in a given storm and at a given location are influenced potentially by shallow water effects. For example, in a given storm on the Grand Banks, the sea-states might for a part of the time history be effectively deep water, and the "TMA" scaling would have no effect, until the stage of wave development provides spectral energy levels in a frequency range which is susceptible of the scaling, leading to significant reduction in total energy and wave height. The preliminary comparison of time histories of wave height and period derived from unscaled and scaled spectra suggests that in most severe storms on the Grand Banks, shallow water effects must be considered to accurately hindcast peak sea-states, and that accurate deep-water hindcasts will provide somewhat conservative results in the water depth range of most interest to the offshore industry. (i.e. less than 100m).

It must be noted that the above approach is only a rough method to qualitatively study the effect of shallow water on the model hindcast; the proper way to deal with the question of the shallow water is to run a shallow water wave model, which is beyond the scope of the present study.

Also note here that this investigation of possible shallow water effects was carried out only to try to explain some of the overprediction by the deep water model when compared with the actual measurements taken in relatively shallower water. However, the production hindcasts (section 6.0) were deep water hindcasts.

5.0 VERIFICATION OF WIND/WAVE HINDCASTS

In order to assess the quality of the wave model predictions, it is necessary to isolate the errors (i.e. bias or any systematic errors) in the input winds which are used to drive the wave model. After the maximum effort has been expended on wind analysis, the wave hindcasts and comparisons should reveal the skill achievable in the hindcasts carried out with the present wave model. In this section, the wind and wave verifications are presented simultaneously in the form of graphical and statistical comparisons.

5.1 VERIFICATION CASES

Ten verification cases were selected; five for the Grand Banks and five for the Scotian Shelf storms. These cases were selected from recent events where more measured data coverage was available (i.e. 1980-1986). The following verification storms were selected:

		Storm Period		
No.	Storm Area	Total Simulation Duration	Kinematic Analysis Duration	MCL #
1.	SS,GB	82011300-82011900	82011412-82011712	467
2.	GB	82021200-82021700	82021400-82021600	474
3.	SS	83021000-83021500	83021200-83021500	487
4.	SS	83102400-83102800	83102418-83102612	493
5.	SS,GB	83112400-83113012	(SS)83112512-83112712 (GB)83112800-83113000	495
6.	GB	83121900-83122400	83122112-83122312	499
7.	SS	84012912-84020312	84013100-84020200	502
8.	SS,GB	85010400-85010900	85010500-85010800	512
9.	GB	85012512-85013012	85012700-85012912	515
10.	GB	85121512-85122112	85121812-85122012	523
11.	GB	86010212-86010612	86010400-86010600	526

NOTE:

Storm #2 (Ocean Ranger) had been adequately treated in the "Royal Commission" study and evaluated in the Mobil Hibernia wave hindcast study (MPL/OWI, 1985). Therefore it will not be evaluated here. It was included in the top 68 storms that were hindcast in this study.

5.2 MEASUREMENTS

Wind speed and direction (also air and surface water temperature) records were obtained from offshore drilling rigs and NOAA buoys, which were in the study area during each of the validation storms. These observations were used for the verification of the modelled winds after being converted to "effective neutral" winds at 20 m above the mean sea level, similar to those used in running the wave model. The MPBL model was used for this purpose. The observed wind at a given rig was compared directly with the hindcast wind at the nearest grid point in the model domain.

The available wave measurements were obtained from automatic wave recording systems (e.g. MEDS and NOAA buoys). In the recent years, a large amount of wave data has been collected from exploratory drilling rigs on the Scotian Shelf and the Grand Banks. These data were obtained from MEDS or directly from offshore operators and from MPL files. A limited amount of 1-D spectra were obtained and used in the evaluation. No directional wave data were available during the selected storm durations. The measured wave data were compared with the hindcast results (i.e. H_s, T_p and wave spectra) at the nearest grid point in the model domain, i.e. no interpolation was used.

A summary of validation sites, water depth, the nearest ODGP grid point, data sources and maps of the validation sites location used in each storm are given in Appendix C.

5.3 EVALUATION METHODS

Comparisons were carried out between wind and wave parameters at the measurement sites and the closest ODGP grid point (no interpolation was carried out). The 3-hourly wind speeds and directions (which correspond to the MANMAR synoptic observation times), and measured wave heights and periods were used in this comparison. The following evaluation methods were applied:

1. Time Series Plots of Hindcasts vs. Observations

Time series of hindcast wind speed (WS) and direction (WD), significant wave height (H_s) and peak period (T_p) were plotted against the corresponding observed values at all measurement sites for the validation storms. Results are presented in Appendix C.

2. Statistical Comparison of Hindcasts vs. Observations

A quantitative statistical analysis was carried out to provide an overall evaluation of the hindcast values. The statistical parameters considered are:

Mean Error (Bias) $= \Sigma(x_1 - x_2)/NPTS$

Mean Absolute Error (MAE) $= \Sigma |x_1 - x_2|/NPTS$

Root Mean Square Error (RMSE) $= [\Sigma(x_1 - x_2)^2/NPTS]^{1/2}$

Scatter Index (%) $= (RMSE/AVE) \times 100$

where x_1 is the hindcast value,
x_2 is the observed value,
AVE is the mean of observed values, and
NPTS is the number of data pairs.

3. Scatter Plots and Linear Regression Analysis

The correlation between observed and hindcast parameters was carried out using linear regression analysis. The correlation coefficient was calculated for each data set at the evaluation sites. Results (i.e. error statistics and scatter diagrams) are given in Appendix C.

The above parameters (in 2 and 3) were calculated for each verification site within the kinematic analysis domain during the kinematic analysis period of each storm. In addition, overall average values of the above parameters were calculated for all sites and all storms as shown in Table 5.1 and Figure 5.1.

4. Peak-to-Peak Comparison

The peak-to-peak comp in particularly important in this type of study where the peaks are selected for extremal analysis. The model-predicted peak values were compared with the measured peak values for each storm. Results are given in Table 5.2. For the 20 minutes continuous wave records, a 7-values moving average of the wave height square was used to provide comparable values to those hindcast (which represent 2 hourly values).

5. Spectral Comparison

A number of wave spectra was selected from available waverider buoy data and compared with the corresponding model spectra. For 20 minutes continuous wave records, an average spectrum was obtained from 7 spectra centred about the hindcast time. The results are shown in Appendix C.

5.4 SHALLOW WATER EFFECTS

As mentioned previously, the ODGP model used in the present study is a deep water model, and the results must be treated accordingly. Initially, the model predictions for each storm were evaluated against the measured data. In general, it was found that the ODGP overpredicted the significant wave height by more than a metre, which is larger than what was expected, especially when using winds of high quality for running the model. This obvious overprediction was thought to be largely due to the shallow water effect, which becomes significant at these extreme wave periods. Other effects are due to the modelled land boundaries effect in the westerly winds, and sheltering effects of Sable Island (which is not included in the model). These effects were checked on a storm by storm basis.

The TMA scaling (Bouws et al., 1985) was used to provide a rough estimate of the effect of water depth on the predicted deepwater waves. An average depth of 80 m was used for Grand Banks storms when waves are travelling from the directions south to west. For the Scotian Shelf, a water depth between 60 to 80 m was used depending on wave direction and site location.

The results of the above analyses are presented in Tables 5.1 and 5.2, and discussed in the next section. (See also Appendix C.)

5.5 RESULTS OF VERIFICATION ANALYSIS

The results of the verification analysis are summarized below. Site locations and data coverage, time series plots of measured versus hindcast values, and verification statistics are given in Appendix C.

In the first step, all sites near selected grid points were identified. Then all unsuitable sites or questionable data sets were discarded to avoid contaminating the verification results. The final verification sites were selected on the basis of data quality and site location. The MANMAR wave data were not used in the wave verification. However, the MANMAR wind data quality is generally good, and were used for the wind verification. The sites on the Scotian Shelf were selected on the basis of water depth and location with respect to Sable Island. Sites were not used in error statistics when sheltered by Sable Island during the storm period.

During the verification process, comparison of the model results to the observed values indicated that the ODGP model tended to overpredict the wave heights at the peak by more than a metre. A look at the wind directions during these storms show winds predominantly from the southwest, west, and northwest. Since the maximum wave heights during the storms were in the order of 10 m and periods greater than 10 s, and most observation sites were on the continental shelf with a depth less than 100 metres, these sites can be considered shallow. Therefore a TMA scaling was applied to the model predictions to investigate possible effects of the shallow water on model results.

A summary of the sites used and analysis done is given below for each storm. Note that no evaluation was done for Georges Bank, due to the lack of waverider buoy data.

Storm 1 (GB, SS): All three available sites on the Grand Banks were selected for the storm verification. Since the winds were predominantly from the southwest and west, a TMA scaling for a depth of 80 m was applied to the model results which were then compared to the measured values. With the TMA scaling, the mean error dropped to less than 0.5m, the RMSE dropped to 0.9m, and the scatter index dropped to 14% for the wave height. For the peak period, the mean error dropped to 0.4 s, the RMSE dropped to 2s, and the scatter index dropped to 18%.

Storm 3 (SS): In the final site selection, the Zapata Scotian site was the only site chosen for the wave verification. The Rowan Juneau site was determined to be too shallow, and the John Shaw site did not have any waverider data. The winds were predominantly from the east and north, i.e. deeper waters up stream, so no TMA scaling was necessary.

Storm 4 (SS): For the wave verification, the Vinland and Bowdrill 2 sites were chosen. The Sedco 709 and Zapata Scotian sites did not have waverider data, only MANMAR logs, and hence were not used in error statistics. The Bowdrill 1 site was outside the study region, and was not chosen for this reason. The winds were predominantly from the east and north, so no TMA scaling was done for these sites.

Storm 5 (SS, GB): In the final site selection, the Bowdrill 2 and Glomar Labrador sites were chosen to represent the Scotian Shelf. The Sedco 709 and Zapata Scotian sites were not selected since no waverider data were available. The Vinland site was not selected because it was sheltered by Sable Island during the first part of the storm. The winds on the Scotian Shelf were predominantly from the south and southwest. At the selected sites, the approaching waves were travelling over water depths of 60 to 80 metres, therefore, a TMA scaling for 80m depth was used at the Bowdrill 2 site, and for 60m depth was used at the Glomar Labrador site. Some sheltering from Sable Island may have occurred at the Glomar Labrador site, but the effects would be minimal since the site was quite a distance from the Island. The resulting statistics for these sites are much improved after TMA scaling was applied.

Storm 6 (GB): Both available sites on the Grand Banks were used in the wave verifications. The winds were predominantly from the west and northwest, so that TMA scaling for a depth of 80m was applied to the model results. The resulting statistics of the TMA scaled waves are much improved.

Storm 7 (SS): On the Scotian Shelf, three sites (Bowdrill 2, Glomar Labrador 1, and Rowan Gorilla 1) were chosen to represent the region, since these were the only available sites with waverider data. The winds during the storm period were mainly from the southwest and west. Hence, the effective depth at the Bowdrill 2 site was 80m, and 60m at the Glomar Labrador and Rowan Gorilla sites. On average, the TMA scaling produced results which closely resembled the measured waves. However, at the Glomar Labrador and Rowan Gorilla sites, the deep water results gave a more accurate prediction of the maximum wave height.

Storm 8 (SS, GB): On the Scotian Shelf, the three sites (Sedco 709, Sedco 710, and Glomar Labrador 1) were selected. During the storm period, the winds were predominantly from the southwest and west. Hence, a TMA scaling was applied to these sites with 60 m effective depth.

On the Grand Banks, all available sites were used. During the storm, the winds were predominantly from the southwest and west and a TMA scaling with an effective depth of 80m was applied.

In the comparison results, it is apparent that the TMA scaling reduces the error in the model predictions.

Storm 9 (GB): On the Grand Banks, all available sites were selected for the wave verification. During the storm period, the predominant winds were from the west, and a TMA scaling for a depth of 80m was applied. Closer agreement between model predictions and measurement was observed as a result of TMA scaling.

Storm 10 (GB): On the Grand Banks, the Bowdrill 2 and Bowdrill 3 sites were selected for the verification, since these were the only available sites with waverider data. The winds were predominantly from the west, but there were short periods when the winds were from the south. As shown in the time series plot of this storm (Appendix C), the ODGP underpredicted the storm peak by over two metres with over 6 hours lag. This storm was then rehindcast after additional care in wind field analysis. However no major improvement in model results was obtained.

This is a particularly interesting storm; it was associated with a rapid propagation of the wind field which was characterized by a rapid rise in wind speed after an abrupt shift in direction. This small scale structure in the wind field propagated at speed close to the wave speed, hence some resonance effect may have occurred. To properly hindcast this storm, sufficient data coverage and extensive efforts are required, which is beyond the scope of this study. In many ways this storm is similar to the Ocean Ranger storm, which was extensively studied in previous hindcast work for Mobil and the Royal Commission.

Storm 11 (GB): On the Grand Banks, the Bowdrill 2 and 3 sites were selected for the verification. The winds were predominantly from the west, with short periods from the south. TMA scaling was also applied to the verification sites.

A summary of the above verification analysis results is given in Table 5.1 and Figure 5.1 (see also Appendix C). Time series plots of wind speed and direction, wave height and period of measured versus hindcast values are given in Appendix C.

Peak-to-Peak Evaluation

To evaluate the model prediction of the maximum significant wave height and peak period during each storm, the model predictions were compared to the measured values at storm peak. It should be noted that the peak-to-peak comparisons in this study were calculated twice: (a) from measured peaks taken as absolute highest sea state in the measured time series, and (b) by smoothing the 20-minute continuous measurements to the time scale of the model (i.e. 2 h). A 7-point moving average was applied to the continuously measured data, then the averaged peak values were compared with the modelled peaks. The results from the two methods are summarized in Table 5.2. As shown, with the exception of storm #10, the model predicted the peak values with high skill. Figure 5.2 shows scatter diagrams of the predicted and measured (average) peak H_s and T_p for all storms at all verification sites considered. The TMA scaling produced closer agreement between the model and observed values (with less scatter and better correlation coefficients, both for H_s and T_p). The results were improved when average peak values were used with TMA scaling.

Spectral Comparison

A number of 1-D spectra was selected for the evaluation of the model hindcast spectra. The selected spectra were taken at or near the peak of the storms.

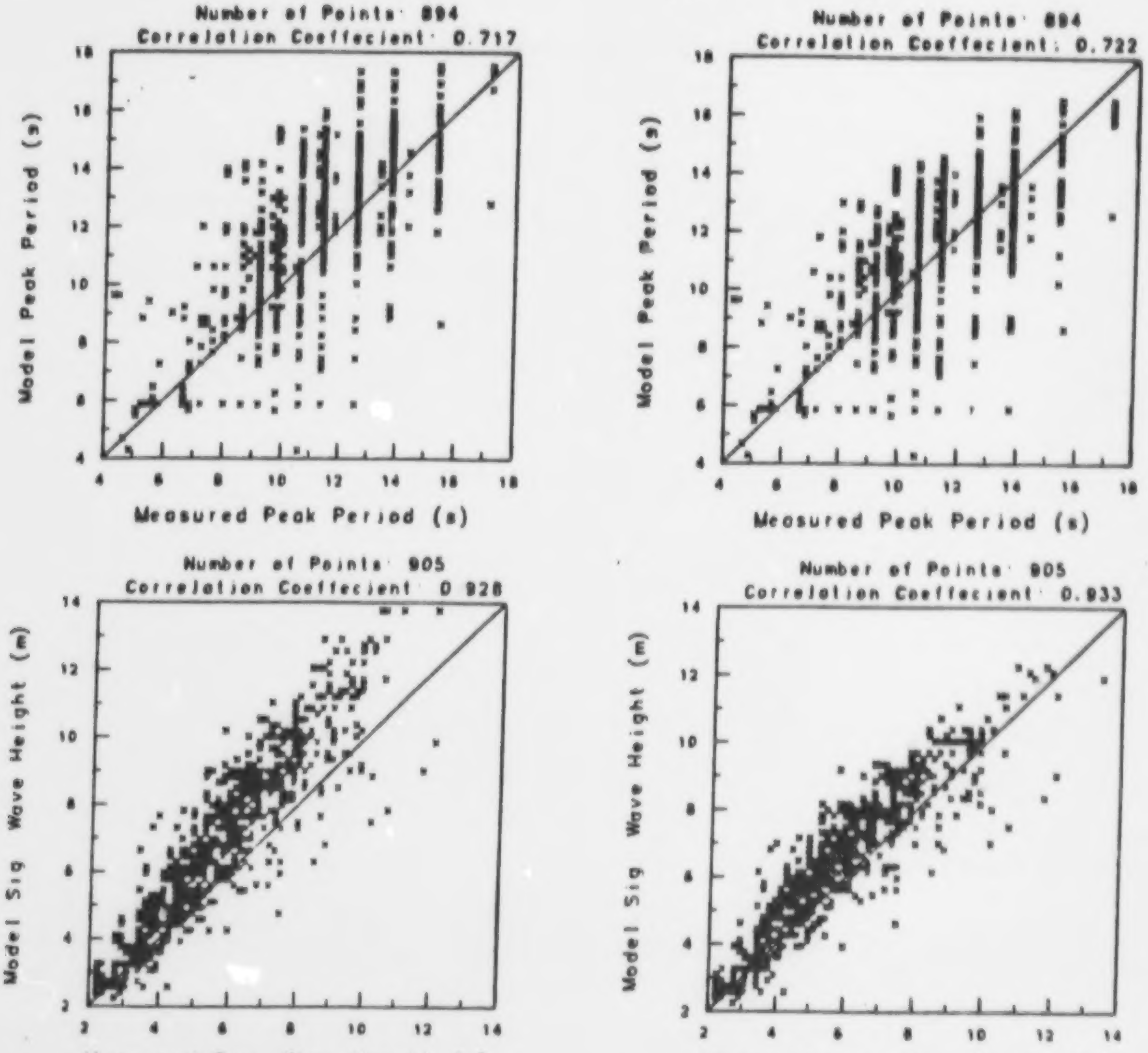
The "measured" spectra shown in Appendix C were obtained from MEDS digital database and MPL archives. As pointed out by Szabo et al. (1989) and shown in the latest Hibernia wave hindcast study (MPL & OWI, 1985), an average of 6 to 7 spectra from continuous 20-minute records would provide the best representative spectra for comparison with wave model predictions. Therefore an average of 7 spectra centred above the ODGP predicted spectra was used in the present evaluation. The comparisons at the peak wave height was emphasized here.

On average, good agreement between the "measured" and predicted 1-D spectra was found, as shown in Appendix C. The agreement is particularly close when the predicted wave height is close to the measured wave height.

Table 5.1 Summary of Error Statistics

	Avg Obs	SD Obs	Avg Mod	SD Mod	Mean Err	Abs M.E.	RMSE	SI	Corr Coeff
	Summary of all model/measured comparisons - Scotian Shelf								
H_s DEEP	4.33	1.92	5.00	2.41	0.66	0.93	1.15	26.57	0.931
TMA	4.33	1.92	4.72	2.14	0.39	0.67	0.81	18.35	0.944
T_p DEEP	9.98	2.25	10.48	2.50	0.50	1.44	1.83	18.35	0.730
TMA	0.98	2.25	10.16	2.22	0.18	1.24	1.62	16.21	0.741
	Summary of all model/measured comparisons - Grand Banks								
H_s DEEP	6.02	2.05	7.31	2.70	1.29	1.44	1.75	29.07	0.912
TMA	6.02	2.05	6.66	2.21	0.64	0.89	1.11	18.40	0.913
T_p DEEP	12.10	2.02	13.06	2.30	0.96	1.70	2.16	17.85	0.607
TMA	12.10	2.02	12.42	2.04	0.33	1.39	1.82	15.07	0.609
	Summary of all model/measured wind comparisons (SS & GB)								
W_s (m/s)	14.56	7.16	14.33	6.61	-0.24	2.79	3.76	25.83	0.854
W_d (deg.)	-	-	-	-	3.02	25.41	44.64	-	-
	Overall Statistics - All storms and regions								
H_s Deep	5.48	2.16	6.57	2.82	1.09	1.28	1.58	28.89	0.928
TMA	5.48	2.16	6.04	2.37	0.56	0.82	1.02	18.66	0.933
T_p Deep	11.43	2.31	12.25	2.65	0.82	1.62	2.06	18.04	0.717
TMA	11.43	2.31	11.71	2.34	0.28	1.34	1.76	15.40	0.722

Significant Wave Heights (H_s) in m
Peak Period (T_p) in s
Wind speed (W_s) m/s



a) Deep Water Predictions

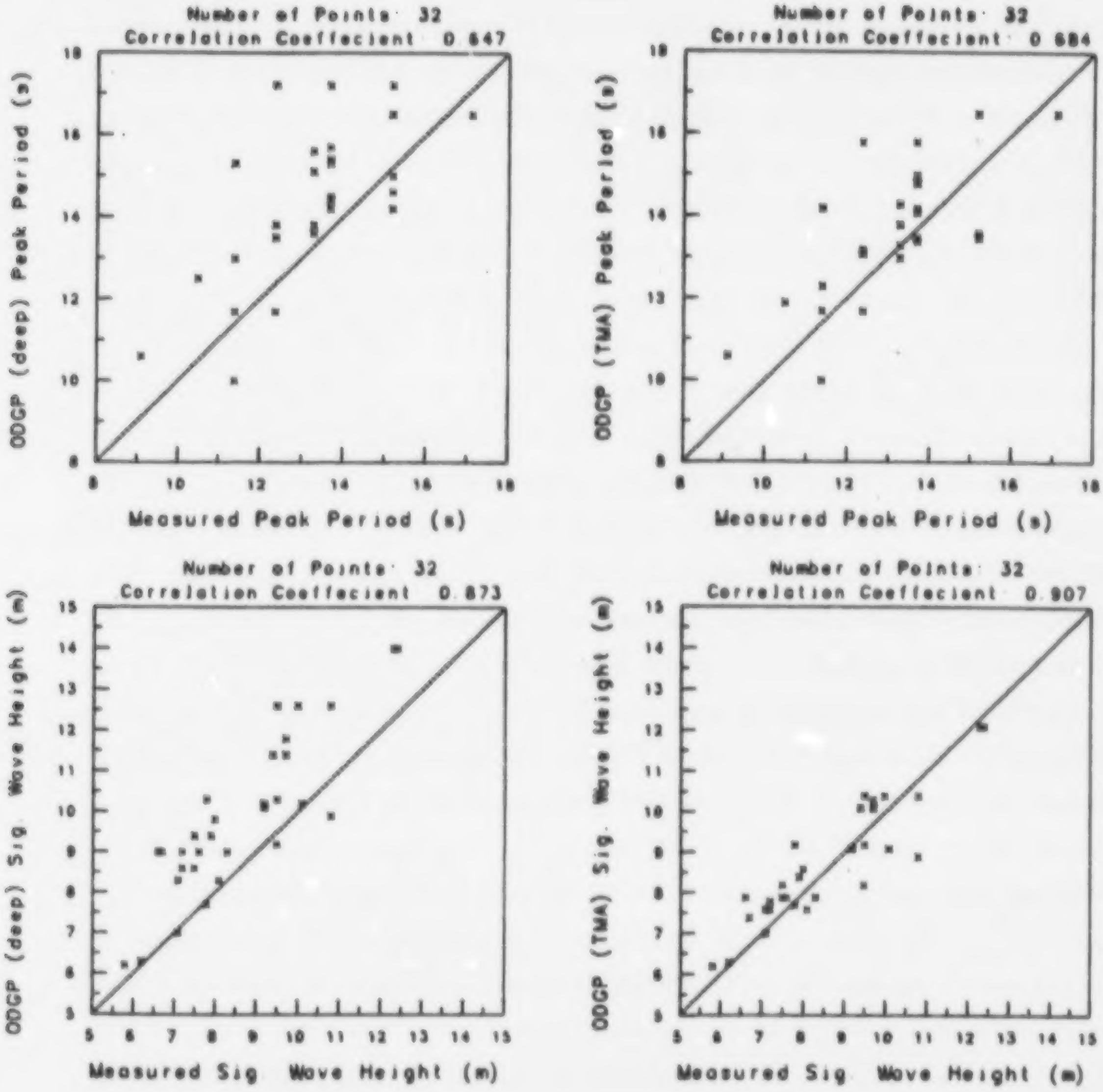
(b) TMA Scaled Predictions

Figure 5.1 Scatter diagrams of measured versus model values for (a) deepwater, (b) TMA scaled values

Table 5.2 Peak-to-Peak Comparison Statistics

	Observation		Model		Mean	AME	RMSE	SI	Corr.
	mean	SD	mean	SD	Err.				Coeff.
No Smoothing of Measured Values									
Ws	25.79	3.27	24.55	1.98	-1.24	2.44	2.88	11.17	0.606
H_s Deep	9.36	1.73	9.89	1.94	0.53	1.06	1.24	13.21	0.820
TMA	9.36	1.73	8.78	1.44	-0.59	0.73	1.05	11.23	0.864
T_p Deep	13.05	1.48	14.49	1.77	1.44	1.83	2.15	16.47	0.531
TMA	13.05	1.48	13.73	1.52	0.69	1.16	1.40	10.70	0.672
After Smoothing of Measured Values									
H_s Deep	8.63	1.63	9.89	1.94	1.26	1.35	1.58	18.27	0.873
TMA	8.63	1.63	8.78	1.44	0.14	0.56	0.70	8.12	0.907
T_p Deep	13.18	1.59	14.49	1.77	1.31	1.59	1.93	14.63	0.647
TMA	13.18	1.59	13.73	1.52	0.55	1.09	1.36	10.28	0.684

Wind speed (W_s) m/s
Significant Wave Height (H_s) m
Peak Period (T_p) s



(a) Deep Water Values

(b) TMA Scaled Values

Figure 5.2 Scatter Diagrams of Measured vs. Predicted Storm Peak Values

5.6 DISCUSSION OF VALIDATION HINDCAST RESULTS

This hindcast study is a logical extension of a series of studies carried out on the East Coast with the basic hindcast methods adapted to this study. In particular, the ODGP models have been used in the simulation of a full three-year period, in the estimation of site-specific extremes at Hibernia, and in support of the CASP and LEWEX/LIMEX studies. The Hibernia study included a substantial validation of hindcast peak sea states in nine (9) storms at Hibernia. In seventeen comparisons, the mean difference between hindcast and measured peak significant wave height (hindcast-measured) was found to be +0.26 m, with an RMS difference of 1.19 m and a scatter index of 12.8%.

Only three of the ten storms used in the present study were included in the Hibernia validation study, and it is interesting to compare the skill achieved in the present hindcasts over the larger area, with the skill achieved in the site-specific study. The most striking difference in the present series is the increase in the mean difference between hindcast and measured peak H_s for the Grand Banks comparisons. The overall mean difference for those comparisons, using the deep water results, is 0.53 m (no smoothing applied) or 1.26 m (with smoothing) as shown in Table 5.2. There is a clear tendency to overspecify peak H_s in the more intense storms, except for storm #10, in which the very rapid apparent build-up in seas on the Grand Banks is not captured and the hindcast peak H_s is lower than measured by nearly 2 m. The scaling of the hindcast peaks for shallow water effect, however, changes the sign of the mean difference, and leads to low errors overall on the Grand Banks (and Scotian Shelf).

The increase in the mean difference for the deep water hindcasts on the Grand Banks may actually be a consequence of more accurate deep water hindcasting in this study over all previous studies. There have been a number of small refinements in the hindcast procedures in this study, each of which could have a slight effect on the mean properties of the hindcasts, but which taken together could lead to a small increase in the peak wave height in a simulated storm. In particular, the wind fields have been calculated on a finer grid and have taken full advantage, in the validation storms, of the rig winds in the kinematic analysis step. The pressure gradients are better resolved on the finer grid, allowing perhaps somewhat higher peak winds. The interpolation of wind fields to two-hour time steps using the moving centers algorithm also better conserves wind maxima on time steps intermediate to map times. In the wave model, the fine mesh grid covers a larger domain than used in previous applications on the East Coast. The time step is reduced to 2 hours from 3 hours, and the CMPE27 source term treatment can produce slightly higher sea states than the CMPE24 algorithm, if the wind field is changing rapidly (such as in storm 10).

The success of the crude attempt to account for shallow water effects through the TMA scaling, suggests that the most accurate hindcasts of severe storms on the Grand Banks will require a shallow water model, even though on a day-by-day basis, the wave regimes on the Grand Banks may be adequately treated as deep water.

In the Scotian Shelf, the comparisons between hindcast and measured sea states are significantly affected by the sheltering effects of Sable Island, which was not resolved in the hindcast model. It is obvious from the time history comparisons, that whenever the wind direction placed the measurement site in the lee of the Island, the hindcast sea states are overspecified. Otherwise, the comparisons are generally excellent. Shallow water effects appear to be secondary to sheltering effects, in determining the skill in the deep water hindcasts. Probably at most measurement sites, the water was deep enough for the spectral content of the sea states excited such that the waves could be considered deep water. Scaling improved the results somewhat at the shallower measurement sites even on the Scotian Shelf. Again the TMA scaling treatment was only a crude way to assess the effect of shallow water on the model predictions. However, an appropriate shallow water wave model will be required to provide accurate hindcasts at shallow water sites.

It can be noted that the peak-peak comparisons based on measured peaks taken as the absolute highest sea state estimated within the measured time series tends to degrade the comparisons, whereas smoothing of the spectra over 6 or 7 consecutive 20 minute samples has increased the agreement between observed and hindcast spectral shapes. However, smoothing of the measurements to the time scale of the model has improved the peak-peak wave height comparisons for TMA scaled values and increased the difference between the model and measured values in the deep water predictions. Smoothing of the spectra provided closer agreement between the "measured" and modelled spectra. Also the comparison was done using only the nearest grid point rather than allowing for spatial variations in the selection of hindcast peaks for comparison. However, as in most applications of this kind, the dominant contribution to hindcast errors is probably the effect of spatially coherent wind field errors, which unfortunately are probably not further reducible, given the present density of surface marine observations and the inherent inaccuracies of ship wind observations.

Overall, the peak-peak comparisons in H_s and T_p indicate skill comparable to the highest reported in previous studies of this kind. The overall scatter index in H_s of 13.2% (11.2% for scaled data) for measured values without smoothing and of 18.3% (8.1 for scaled data) after smoothing, is close to the scatter index of 11.9% in the ODGP hindcast comparisons reported by Reece and Cardone (1982), and to the skill reported for even third-generation model hindcasts in mid-latitude Northern Hemisphere basins.

Again, this study was not meant to provide shallow water hindcasts. A proper shallow water model should be used to enhance the results presented in this study. This area requires additional future work.

6.0 PRODUCTION HINDCAST

6.1 EXTRATROPICAL STORMS HINDCAST

The selected 68 extratropical storms were hindcast using the techniques and procedures described in earlier sections of this report. Again, only the deep water version was used for the production hindcast. A list of the final top 68 extratropical storms is given in Table 6.1. The table provides the MCL reference number, storm hindcast period, and summary of hindcast peak significant wave height (H_s), corresponding peak period (T_p) and vector mean wave direction (°T going towards) at three grid points representing the three regions (i.e. grid point #3498 for EB, #3590 for SS and #3744 for GB).

The results of the wind and deep water wave hindcast were archived and delivered to the AES and MEDS on magnetic tapes, where they were implemented into those organizations respective analysis systems. The archived data are:

1. Winds
   All gridded wind fields (every 2 hours) at all grid points (coarse and fine). The parameters archived are: wind speed in knots (20-m effective neutral winds) and wind direction (in degrees true meteorological convention).
2. Waves
   - Summary of wave fields (H_s, T_p and vector mean direction) at all coarse and fine grid points every 2 hours.
   - Spectral data file which contains a header line and the 2-D spectral variance (15x24 fields) at all grid points in the study areas (118 points) every 6 hours. The spectral file contains date (YRMODYHR), grid point number, wind speed (kts) and direction, U_*, H_s(m), T_p(s), vector mean direction and directional spectral variance (m^2).

For each storm, the peak significant wave height and corresponding peak period, wave mean direction, wind speed and direction were compiled, and other parameters were computed (i.e. ratios of H_{max}/H_s and H_c/H_s) at each grid point in the study area. This information was used in the extremal analysis as described in Chapter 7.0.

Table 6.1 List of Production Hindcast Storms

NCL#	REGION	STORM START-END	GRID PT 3498 Hs (m)	Tp (s)	VMD (to)	GRID PT 3590 Hs (m)	Tp (s)	VMD (to)	GRID PT 3744 Hs (m)	Tp (s)	VMD (to)
40	SS,GB	59020612-59021012	4.3	9.3	94.	5.7	9.8	131.	9.3	13.4	84.
54	SS,GB	60010900-60011300	6.1	10.5	170.	7.5	12.2	163.	8.8	12.2	116.
70	SS,GB	61011912-61012312	7.0	11.9	306.	8.9	14.9	78.	11.1	16.6	54.
85	SS,GB	61121412-61121912	5.8	10.4	155.	6.8	11.0	153.	10.3	13.5	111.
95	SS	62030600-62030912	8.2	12.0	249.	6.2	11.8	247.	5.2	10.8	191.
102	SS	62111412-62111912	8.1	11.9	198.	7.2	11.4	278.	6.3	12.5	13.
106	SS	62123000-63010218	6.3	10.6	121.	5.9	10.5	328.	6.4	11.8	304.
121	GB	63111400-63111818	3.6	9.1	112.	5.4	10.5	135.	10.3	14.5	64.
124	SS,GB	63121900-63122118	7.6	11.6	149.	9.4	13.3	74.	9.1	15.5	56.
129	SS,GB	64011212-64011718	7.3	11.7	178.	7.0	10.8	157.	10.9	14.3	95.
132	SS,GB	64020800-64021018	6.1	11.0	94.	8.8	12.3	69.	9.3	14.6	63.
140	SS,GB	64031512-64031912	5.5	9.6	110.	5.8	11.7	51.	9.2	13.5	155.
147	SS	64113000-64120312	8.6	11.9	98.	10.0	14.4	47.	6.2	13.6	62.
151	GB	65012112-65012512	5.6	9.4	207.	4.6	9.2	316.	7.4	12.9	136.
169	SS,GB	66010812-66011212	6.6	10.7	163.	7.6	11.8	168.	8.8	12.4	171.
172	SS,GB	66012612-66013012	8.9	12.2	102.	7.8	14.5	81.	9.6	12.5	304.
174	SS,GB	66021318-66021812	6.3	10.8	60.	6.9	12.6	74.	12.0	15.1	138.
189	SS,GB	67022100-67022500	10.1	13.3	90.	10.3	14.7	56.	12.6	16.8	49.
195	SS	67042700-67050200	8.9	12.3	216.	8.0	12.1	289.	3.1	13.0	6.
200	SS,GB	68010418-68010800	6.8	10.4	143.	8.4	12.3	97.	10.1	15.3	68.
215	SS	69020900-69021218	6.7	11.5	332.	7.2	11.8	329.	5.6	11.3	345.
223	SS	69122600-69123012	7.0	11.9	80.	7.5	12.0	330.	6.4	11.2	143.
226	SS,GB	70012000-70012400	5.3	9.5	161.	6.1	10.1	150.	9.8	14.3	130.
235	SS,GB	70122600-70123000	6.8	10.7	126.	9.9	14.7	40.	7.9	15.7	47.
237	SS,GB	71011518-71011918	4.9	9.5	208.	5.9	9.9	132.	12.0	15.7	57.
241	SS	71030300-71030700	11.0	15.2	72.	10.5	16.9	61.	7.4	12.2	158.
260	SS,GB	72021812-72022200	7.5	13.5	71.	7.7	13.3	19.	7.2	13.1	15.
265	SS,GB	72032612-72033100	5.1	10.4	207.	7.0	11.3	223.	4.7	13.6	13.
282	SS,GB	72121512-72121912	7.5	11.7	114.	8.6	13.5	84.	8.8	15.1	70.
303	SS,EB	73032112-73032500	8.2	12.7	236.	7.7	11.9	251.	4.8	10.7	288.
309	SS,GB	73102600-73102912	5.3	10.7	269.	6.4	10.5	153.	10.8	15.0	65.
310	SS	73110100-73110512	7.9	12.0	99.	8.6	13.4	70.	7.6	14.8	65.
317	GB	74010200-74010700	3.0	8.2	159.	4.3	9.6	140.	9.6	13.6	130.
325	SS,GB	74020400-74020800	6.9	10.8	169.	8.1	10.7	94.	7.0	10.9	114.
326	SS	74021612-74022000	6.7	10.5	104.	8.1	12.8	6.	6.5	12.6	21.
329	SS,GB	74031012-74031412	6.1	10.5	148.	8.4	11.6	158.	10.0	14.6	37.
377	SS,GB	76031600-76032000	8.7	12.3	96.	10.2	14.5	65.	12.4	17.2	65.
384	SS,GB	76110512-76111000	5.9	10.7	163.	7.3	12.3	83.	7.0	13.7	66.
386	SS	76111812-76112300	5.6	10.4	116.	7.7	11.4	98.	7.4	11.9	324.
394	GB	77011900-77012300	3.8	8.6	125.	5.9	10.8	94.	11.0	15.8	52.
395	SS,GB	77020512-77021012	5.4	9.9	190.	7.8	11.5	151.	9.8	15.0	70.
404	SS	78010812-78011212	9.1	13.8	46.	8.4	13.8	38.	5.5	13.8	55.
408	GB	78030100-78030500	5.3	9.4	144.	5.8	9.5	158.	11.5	13.8	115.
421	GB	79020300-79020712	7.1	11.4	116.	6.7	11.8	102.	6.1	12.4	167.
NEW	EB	80011412-80011812	8.3	13.3	248.	7.4	12.0	271.	3.2	8.2	189.
433	SS,GB	80020612-80021012	7.6	11.3	209.	7.6	11.7	225.	8.1	12.9	208.
434	SS,GB	80021000-80021400	4.1	8.4	179.	7.3	10.9	196.	8.4	11.8	118.
442	SS,GB	80111812-80112212	7.3	11.2	153.	8.0	11.2	132.	9.5	12.3	134.
443	SS	80112106-80112418	7.0	10.7	170.	6.8	11.0	229.	6.0	10.9	273.
451	SS	81030500-81031000	7.0	13.1	213.	8.9	13.9	230.	8.7	13.7	234.
453	SS	81031512-81032000	8.0	11.8	92.	9.3	14.6	36.	8.4	14.1	59.
463	SS,EB	81120412-81120812	6.9	10.8	109.	6.5	12.8	358.	4.1	14.5	30.
464	SS,GB	81121500-81121912	8.3	13.1	66.	9.6	14.6	62.	9.4	15.6	69.
465	SS,GB	81122912-82010300	8.0	11.9	151.	8.6	12.1	146.	10.2	14.7	187.
467	SS,GB	82011300-82011900	7.6	11.0	102.	9.1	13.4	58.	12.6	17.2	58.
474	SS,GB	82021200-82021600	4.7	8.6	156.	7.6	10.7	112.	13.4	16.8	44.
487	SS,GB	83021000-83021500	6.4	10.4	285.	6.3	10.1	142.	8.8	11.9	109.
488	SS,GB	83021506-83021900	5.8	11.1	258.	5.3	10.1	205.	10.3	13.2	210.
493	SS	83102400-83102800	4.9	9.8	213.	7.7	11.7	242.	5.7	13.2	2.
495	SS,GB	83112400-83113012	8.4	12.7	84.	9.7	14.6	66.	10.2	14.6	155.
499	GB	83121900-83122400	3.8	9.2	159.	8.1	13.2	156.	13.3	16.4	166.
502	SS	84012912-84020312	7.3	11.6	59.	8.6	13.5	57.	6.3	12.2	70.
506	SS	84032812-84040112	8.2	13.1	201.	7.5	11.8	256.	6.8	11.0	98.
512	SS,GB	85010400-85010900	6.3	10.6	143.	8.6	12.5	93.	9.0	15.3	64.
515	SS,GB	85012512-85013012	4.7	9.4	135.	6.4	11.5	94.	11.4	15.4	64.
523	GB	85121512-85122112	5.7	10.4	115.	6.7	11.2	87.	9.9	13.6	86.
526	GB	86010212-86010612	6.3	10.6	126.	7.2	11.0	61.	9.2	15.1	61.
NEW	SS	88030700-88031012	4.0	9.2	163.	6.6	10.0	172.	7.3	11.9	324.

6.2 GEORGES BANK TROPICAL STORMS HINDCAST

The tropical storm hindcast for Georges Bank was described in detail in a separate pilot study report entitled "Georges Bank Tropical Storm Hindcast", (Volume III of this report). A special cyclone version of the ODGP was used. For convenience, the model domain is shown in Figure 6.1, however, the reader should refer to the above referenced report for a detailed description of the model and hindcasting procedures used.

Due to budget limitations, only a total of ten storms were hindcast. Table 6.2 provides a list of the 10 storms and a summary of the hindcast results at selected grid points on Georges Bank. This includes the maximum hindcast significant wave height and associated parameters such as wind speed and direction, peak period, and vector mean wave direction.

As shown in Table 6.2, a wide range of sea states was evidently specified in these hindcasts. By far, the most severe storm was the hurricane of September, 1944 in which a combination of location, intensity and extent of the fetch zones of strongest winds to the right of the centre, coupled with the storm translation speed to produce a strong resonant growth of sea state. The storm forward speed appeared to strongly influence the stage of wave development reached in hurricane Gerda, but in the opposite sense where the hindcast peak sea state was slightly greater than 5 m despite the strong peak winds specified. In the remaining storms the peak significant wave height varied between 5 and 9 m.

This population of 10 storms may yield a reasonable estimate of the relative importance of the tropical and extratropical storms on the extreme wave climate at least in the western Georges Bank. However, over the eastern Georges Bank and the border between Georges Bank and Scotian Shelf, additional hindcasts would have to be carried out, and for those hindcasts, the grid system needed would have to be extended eastward.

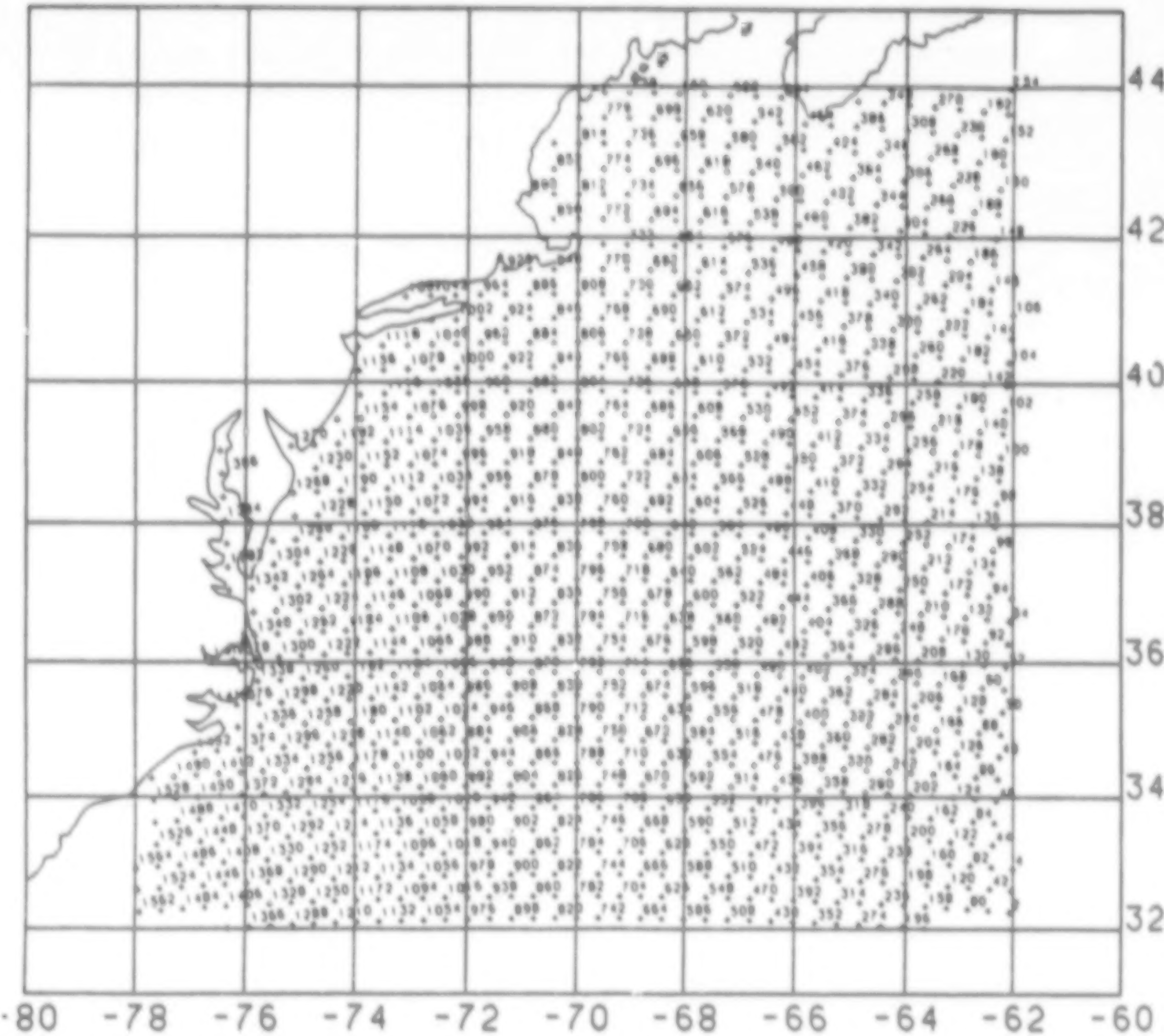


Figure 6.1 Tropical Cyclone Hindcast Model Grid System

Table 6.2 List of Georges Bank Tropical Cyclones (Hurricanes)

Maximum Significant Wave Height and Associated Parameters

Storm #	Name	YYMM	Grid Point #	WS	WD	HS	TP	VMD
1	Sept. '38	3809	496	16.00	157.0	4.67	10.34	331.0
			617	6.84	205.3	5.22	10.97	8.6
			695	18.01	166.6	5.73	11.33	332.0
2	Aug. '40	4008	617	32.57	185.4	9.08	12.46	9.7
			695	27.85	46.8	7.34	12.93	329.5
3	Sept. '44	4409	617	27.81	200.8	10.92	17.60	21.2
			695	31.53	203.7	12.21	17.50	19.3
4	Barbara	5308	496	24.59	220.7	7.55	12.78	33.4
			617	13.97	10.8	5.19	12.39	1.1
			695	13.09	22.3	4.50	12.19	351.8
5	Carol	5309	383	23.65	184.7	8.11	13.02	7.5
			496	25.29	187.1	8.81	13.68	6.7
			617	28.69	131.4	8.57	14.49	332.5
6	Edna	5409	617	10.47	263.7	6.54	16.57	30.1
			695	23.44	225.7	7.23	14.04	13.2
7	Donna	6009	496	14.20	156.3	3.52	8.54	325.7
			617	4.35	271.4	4.51	16.16	16.9
			695	8.22	268.9	4.96	16.23	22.9
8	Daisy	6210	383	21.78	143.3	8.58	13.66	327.4
			496	5.17	166.3	7.97	13.30	311.6
			617	8.15	85.9	7.54	12.82	290.9
			695	14.30	21.6	6.90	12.12	169.4
9	Gerda	6909	383	3.89	237.0	3.66	8.83	32.2
			496	3.04	229.2	4.14	9.63	38.4
			617	34.88	165.2	5.27	8.75	338.7
			695	16.97	289.0	3.88	9.20	331.0
10	Gloria	8509	496	7.61	220.0	3.61	14.23	27.0
			617	7.82	234.6	4.58	14.79	26.4
			695	18.59	192.8	5.16	10.59	354.1

WS - wind speed (metres/second)
WD - wind direction (from which/degrees)
HS - significant wave height (metres)
TP - peak period (seconds)
VMD - vector mean direction (to which/degrees)

A comparison of these results with the hindcasts of extratropical (winter) storms in the Georges Bank shows that the tropical cyclones can generate sea states of comparable magnitude. This suggests that both storm types should be considered, particularly for description of the extreme wave climate for rare recurrence intervals (i.e. ≥ 50 years). The above hindcast population is not large enough to warrant accurate estimation of the extreme climate of tropical storms on Georges Bank.

The most striking feature of the hindcast population presented here is the hurricane of September 1944, with a peak significant wave height exceeding 12 m. This is by far the highest hindcast value in both tropical and extratropical populations on Georges Bank. This storm is a unique, one time storm that was characterized by its fast moving nature, at the wave group velocity, which resulted in a strong resonant growth of sea state. This is somewhat similar to the Ocean Ranger storm which affected the Grand Banks. The model results are extremely sensitive to the speed of the storm, and the hindcast values would need to be verified before being considered with high confidence. This phenomenon requires detailed study, which is beyond the scope of this study.

7.0 EXTREMAL ANALYSIS OF HINDCAST DATABASE

7.1 BASIC APPROACH

The wave model provided time histories of the following quantities at each grid point of the fine grid, which are used in the statistical analysis of extremes:

H_s = significant wave height
T_p = spectral peak period
θd = vector mean wave direction
W_s = wind speed (2-hour average at 20 m elevation)
θw = wind direction

The basic approach was to carry out site specific extremal analysis of hindcast peaks-over-threshold, at each fine grid location. Site averaging was not considered necessary or desirable for the following reasons:

1) a large number of storms were hindcast, thereby providing a reasonably large population of peaks at each grid location;

2) the meteorological properties of storms responsible for wave generation vary gently across basins. This tends to minimize the kind of sampling variations which site averaging is intended to suppress; and

3) the site specific approach may preserve real variations in extremes of wave height and period, associated with fine-scale variations in the complicated shoreline geometry which bounds the three areas of interest.

The objective of the analysis was to determine long term statistical distributions of significant and maximum individual wave height, crest height, and associated wind speed, for subpopulations of storms stratified into sectors of wave approach direction for selected grid points and omni directional extremes at all points. It was found, however, that no more than three broad directional sectors could be justified at any point based upon the given hindcast population of storms.

Finally, estimates were provided of extremes for quantities which were not extrapolated, such as T_p, and quantities extrapolated, such as H_s. Correlations were developed from the hindcast data at each grid point between such quantities.

In the remainder of this section, a more detailed description of each of the key steps of the statistical analysis is given. The statistical models and fitting techniques are well established and have been described in several previous studies (e.g. Muir and El-Shaarawi, 1986).

7.2 CALCULATION OF MAXIMUM WAVE HEIGHT AND CREST HEIGHT

It is by now well known that the statistics of individual wave heights and crest heights in naturally occurring sea states deviate from predictions of the theoretical Rayleigh distribution. A large number of alternative distributions have been proposed. We have adopted the empirical distribution of Forristall (1978) for maximum individual wave height, and the Jahns-Wheeler distribution with Haring, Osborne, and Spencer's (HOS) empirical constants (Haring and Heideman, 1978) for crest height in a wide range of water depths. HOS have also proposed a distribution of maximum individual wave heights which nominally provides maximum heights about 2 percent lower than Forristall's, but whose constants may be adjusted slightly to provide essentially the same results as Forristall (1978).

The various distributions cited above provide estimates of maximum wave height (H_{max}) and crest height (H_c) in runs of n individual waves, expressed usually as zero-crossing waves. In our standard approach, we use Borgman's (1973) integral expression to account for the effect of the actual buildup and decay for each individual storm on the effective number of waves in a storm at a site. This expression used significant wave period, T_s, to relate the period properties of the seaway to the effective number of individual waves. Other approaches have included the use of an average normalized buildup and decay for all storms, or the simple adoption of a constant storm duration. The computation may also be carried out with different relationships between T_s and zero-crossing period, T_z, and properties of the hindcast spectrum, such as T_p or the spectral moments.

In the calculation of H_{max} in this study, the distribution of Forristall (1978) and the method of Borgman (1973) was applied throughout. The adopted H_{max} at each site and in each storm was taken as the median of the fitted distribution. This method uses the significant wave period, T_s, directly from the hindcast spectrum as computed from the zeroth and first moments (M_0 and M_1).

In the calculation of H_c, the method of HOS was adopted, except that as for H_{max} the actual buildup and decay in each storm was used following the method of Borgman (1973). In this calculation, T_z was calculated from T_p using the constant ratio T_z/T_p of 0.74 found empirically to characterize storm sea states in extratropical storms.

In particular the program evaluates Borgman's (1973) integral:

$$\Pr\{H \leq h\} \quad = \quad \exp \int_{t_a}^{t_b} \log \left[1 - e^{h^2/a^2(t)}\right] \frac{dt}{T(t)}$$

where H is the largest wave height; a^2 is the mean square height taken as a function of time, t; t_a and t_b are the beginning and end of the storm; and T(t) is the wave period, taken here as the significant wave period. The equation shown incorporates the Rayleigh probability distribution function.

The integral was actually evaluated for the following distributions of individual wave height, crest height, and wave period T:

individual wave height:

$\Pr\{H > h\} = \exp\left[-1.08311(h^2/8M_0)^{1.063}\right]$ (Forristall); $T = M_0/M_1$

crest height:

$PR(H > h) = \exp[(-h^2/2M_0)(1 - 2.4909z + 0.57z^2)]$, where h is crest height, d is water depth, and $z = h/d$ (Haring et al.);
$T = .74\ T_p$

Since the model hindcasts assumed deep water physics, water depth limitations were ignored in the calculation of crest height. The median of the resulting distribution was taken as the maximum expected single peak height in the storm.

7.3 EXTREMAL ANALYSIS METHODS

The objective of the extremal analysis was to describe extremes at all contiguous grid locations in Georges Bank, Scotian Shelf, and Grand Banks of the following variables (see Figure 7.1):

- H_s versus risk (i.e. annual exceedance probability or return period)
- W_s versus risk (wind speed which corresponds to the peak H_s in each storm).

At a selected subset of grid locations (25 points) a more detailed analysis of the extremes was carried out in order to determine:

1. effective ratios of H_{max}/H_s and H_c/H_s based on the analysis described in Section 7.2;
2) H_{max} and H_c versus risk (or return period); and
3) peak spectral periods T_p associated with peak H_s from the relation $T_p = A\ (H_s)^B$.

At three "representative" grid locations (i.e. one for each region), a further analysis of the extremes was considered. This included sensitivity of extremes to assumed distribution (i.e. Gumbel vs. Borgman), fitting thresholds, and stratification of extremes on directional sector of wave approach.

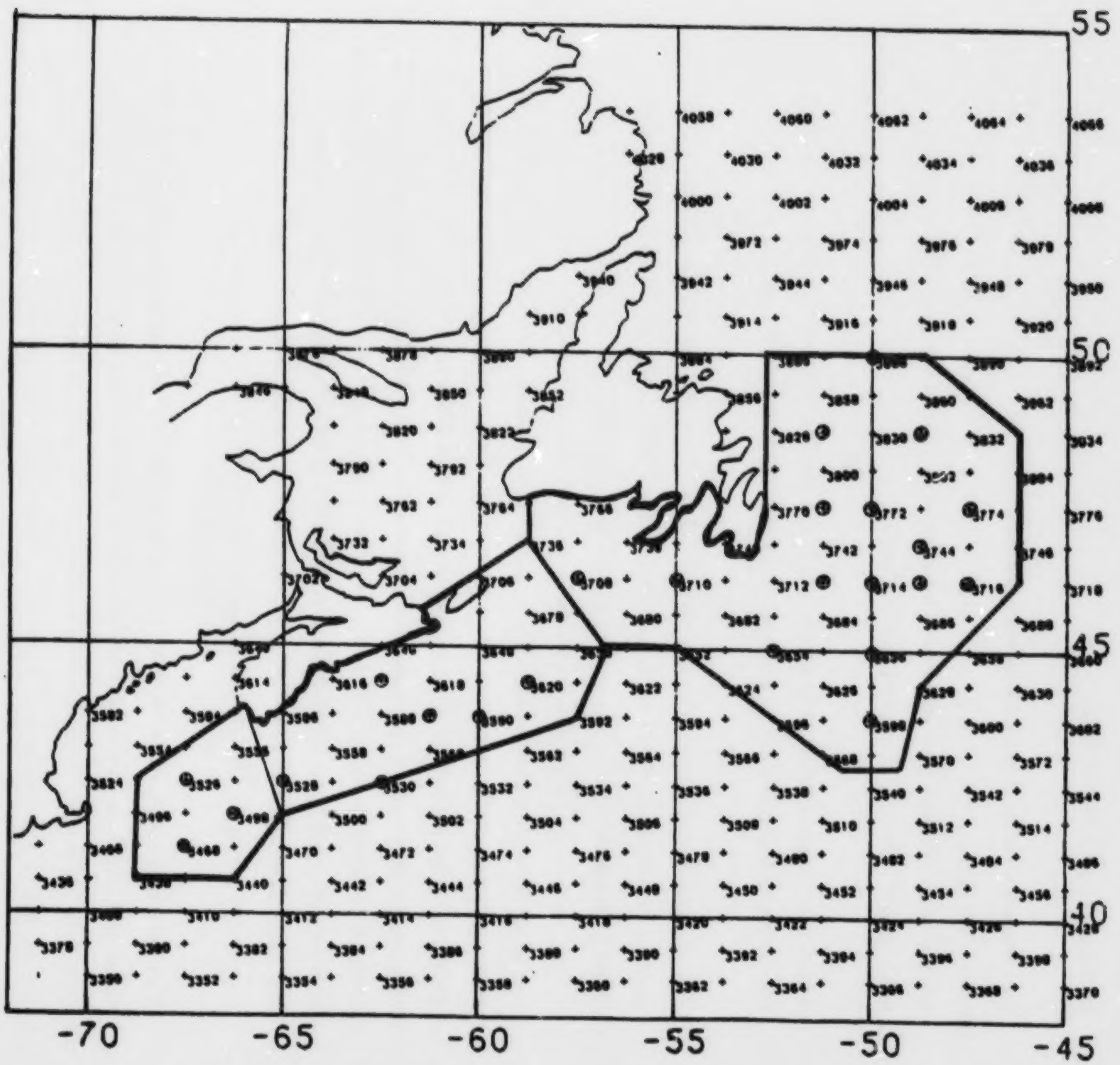


Figure 7.1 Wave Model Grid numbering system in the study area
(o) selected points for detailed analysis

The results of the above analyses were presented in both tabular and graphical forms. The following methods were applied in the analysis.

Extreme Value Distributions

Two extreme value distributions were tested:

GUMBEL: $\Pr\{x \le X\} = \exp[-\exp(-(x-a)/b)]$
BORGMAN: $\Pr\{x \le X\} = \exp[-\exp(-(x^2-a)/b)]$

where x is the parameter to be fitted (e.g. H_s); a and b are constants determined from the fitting of the hindcast data.

The recommended distribution is the Gumbel. The chosen fitting scheme is the method of moments. This is in line with what AES use in their Marine Statistics (MAST) System.

For most environmental data, the Gumbel distribution, fitted by the method of moments has been accepted as appropriate for representing the probability distribution for extremes. As described by Muir and El-Shaarawi (1986), the method of moments is simple, robust, and is unbiased for the Gumbel type distribution. The method involves equating the sample moments (i.e. mean and variance) to the moments derived from the distribution and solving for the estimated parameters. In the present study, the so-called plotting position was determined using the "exact" expression given by Carter and Challenor (1983).

The Borgman distribution with method of moments was also applied to the subset of three grid locations to assess the sensitivity of results to the type of distribution used.

Return Period

The return period, T, is calculated from the cumulative distribution function:

$$P_T = 1 - N/nT$$

where n is the number of samples from N years. Correlating the candidate distribution, $Pr\ \{x \leq X\}$, to the above distribution of return period T yields:

$$X_T = [a - b \ln(-\ln(P_T))]^C$$

where c = 1 for Gumbel and 0.5 for the Borgman.

Numerical Solution

The Gumbel distribution fitted to the extreme value series (whether annual maximum or peak-over-threshold) by the method of moments is simply represented by:

$$X_T = x_{mean} + K_T . s$$

where X_T is the value of the variable equalled or exceeded once in the return period T; x_{mean} and s are the mean and the standard deviation respectively, of the hindcast series of extremes; K_T is a frequency factor dependent on the return period obtained from:

$$K_T = -(\sqrt{6}/\pi)\ \{0.5772 + \ln[\ln(T/(T-1))]\}$$

Confidence Limits

The extreme values calculated from the above approach represent the "best fit" estimates. However it is necessary to provide the confidence intervals for this estimate (e.g. 90% or 95%). The confidence interval is given by the range:

$$X_T - t(\alpha)s_e \text{ to } X_T + t(\alpha)s_e$$

where: $s_e = \beta \,.\, s/n^{1/2}$

$\beta = (1 + 1.14\,K_T + 1.1\,K_T^2)^{1/2}$

and $t(\alpha)$ is the student t-distribution value corresponds to confidence level α for n samples.

The span of the upper limit (UL) to Lower Limit (LL) values normalized by the best fit (i.e., [UL - LL]/mean) is a relative measure of the goodness-of-fit. It should be noted that these confidence limits address only statistical characteristics of input data, and not the possible errors in storm selection and hindcast accuracy.

All other parameters (i.e. T_p, H_{max} and H_c) are derived from the estimated extreme H_s for given return periods (or probability of occurrence). The derived values are based on the mean or best-fit values of H_s and the methods described in the previous section. The above equations were used to provide the desired extremes both in tabular and graphical forms as shown in the following section.

7.4 RESULTS - SENSITIVITY ANALYSIS

The results from the 68 storms hindcast were input to the extremal analysis program. At each grid point the predicted peak H_s (and other corresponding parameters) was arranged in a descending magnitude for all 68 storms. The top 30 storms (or the number of storms above a given threshold) were identified and used in the extremal analysis at each grid point in the study area (i.e. a total of 119 points, as shown in Figure 7.1).

For detailed analyses, three grid points were selected to represent the regions:

- Georges Bank: G.P.#3498 at 41.875°N, 66.25°W
- Scotian Shelf: G.P. #3590 at 43.750°N, 60.00°W
- Grand Banks: G.P. #3744 at 46.875°N, 48.75°W

For each of the above 3 locations, a list of the 68 storms sorted by peak H_s (in descending form) is given in Appendix D. The results of the extremal analyses are presented below.

7.4.1 Gumbel versus Borgman Distributions

Peak significant wave heights in the top 30 storms were used in the extremal analysis using Gumbel and Borgman distributions. The results are presented in Figures 7.2, 7.3 and 7.4 for EB, SS and GB, respectively. As shown, the two distributions provide similar results at low return periods (i.e. < 25 years) and slightly higher values from Gumbel at large return periods (50-100 years), e.g. about 2% at 100 year return period.

7.4.2 Effect of Wave Height Threshold

Extremal analysis was carried out with different wave height thresholds for each population at the three grid points. In the selection of the thresholds, a minimum number of 20 storms was maintained. The results are presented in Table 7.1.

It was found, in general, the lower thresholds provided slightly higher extreme wave heights, in the order of 2-3%, than those calculated with higher thresholds, at large return periods (50-100 years).

As shown in Table 7.1, the top 30 storms provided thresholds of about 7.0 m for Georges Bank, 7.7 m for Scotian Shelf, and 9.2 m for the Grand Banks locations.

It can be concluded from the above that the extremal analysis results are slightly affected by the type of distribution tested and the threshold value used. In the final analysis the Gumbel distribution was used with the top 30 largest wave heights at each grid point in the study area.

Georges Bank
Grid point 3498 – 41.88 N, 66.25 W

GUMBEL – Method of Moments

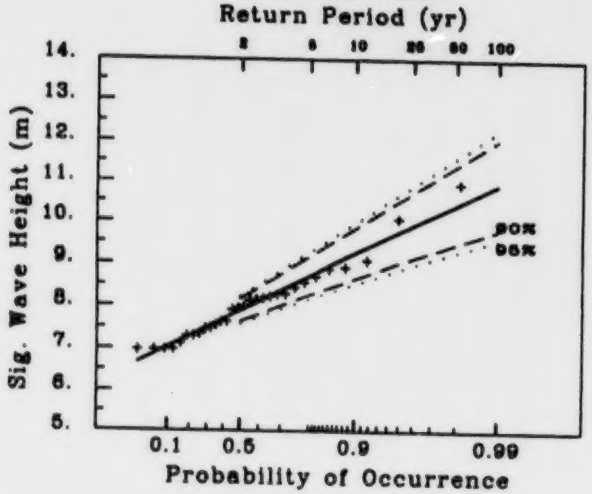
30 storms
Wave height threshold = 6.96 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	7.9	8.2	12.2	14.7	8.2
5	8.7	9.2	12.7	16.2	9.0
10	9.3	9.8	13.1	17.2	9.6
25	9.9	10.7	13.5	18.5	10.3
50	10.4	11.4	13.9	19.4	10.8
100	10.9	12.1	14.2	20.3	11.3

Tp, Hmax, and Hc were calculated using

$Tp = 4.626\ Hs^{0.468}$
$Hmax = 1.860\ Hs$
$Hc = 1.036\ Hs$

Correlation = 0.99



Georges Bank
Grid point 3498 – 41.88 N, 66.25 W

BORGMAN – Method of Moments

30 storms
Wave height threshold = 6.96 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	7.9	9.0	12.2	14.8	8.2
5	8.8	10.2	12.8	16.3	9.1
10	9.3	10.9	13.1	17.3	9.6
25	9.9	11.8	13.5	18.4	10.3
50	10.3	12.4	13.8	19.2	10.7
100	10.7	13.0	14.0	20.0	11.1

Tp, Hmax, and Hc were calculated using

$Tp = 4.626\ Hs^{0.468}$
$Hmax = 1.860\ Hs$
$Hc = 1.036\ Hs$

Correlation = 0.98

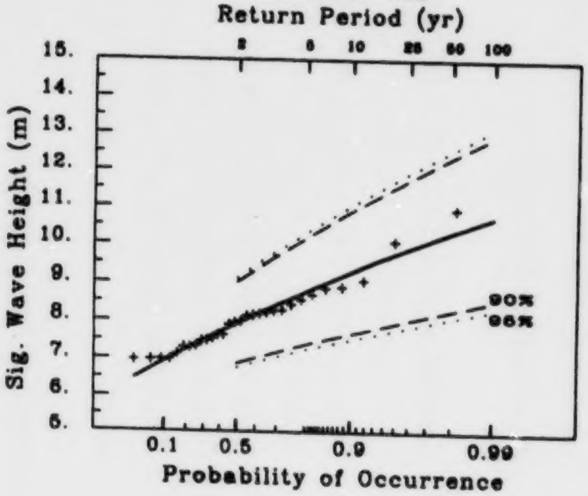


Figure 7.2 Gumbel vs. Borgman - Georges Bank

Scotian Shelf

Grid point 3590 - 43.75 N, 60.00 W

GUMBEL - Method of Moments

30 storms

Wave height threshold = 7.72 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.7	8.9	13.1	16.1	9.0
5	9.4	9.8	14.1	17.4	9.7
10	9.9	10.4	14.7	18.3	10.2
25	10.5	11.2	15.6	19.4	10.8
50	10.9	11.8	16.2	20.3	11.3
100	11.4	12.4	16.8	21.1	11.8

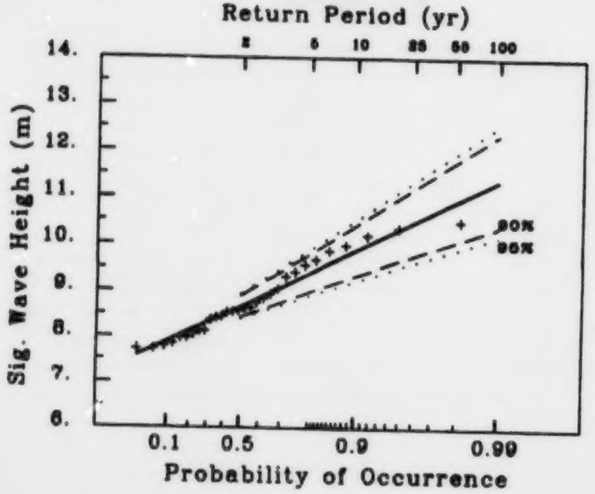
Tp, Hmax, and Hc were calculated using

$Tp = 1.802\ Hs^{0.916}$

$Hmax = 1.857\ Hs$

$Hc = 1.036\ Hs$

Correlation = 0.98



Scotian Shelf

Grid point 3590 - 43.75 N, 60.00 W

BORGMAN - Method of Moments

30 storms

Wave height threshold = 7.72 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.7	9.7	13.1	16.2	9.0
5	9.4	10.5	14.1	17.5	9.7
10	9.9	11.4	14.7	18.3	10.2
25	10.4	12.2	15.5	19.3	10.8
50	10.8	12.8	16.0	20.0	11.2
100	11.2	13.3	16.5	20.7	11.6

Tp, Hmax, and Hc were calculated using

$Tp = 1.802\ Hs^{0.916}$

$Hmax = 1.857\ Hs$

$Hc = 1.036\ Hs$

Correlation = 0.99

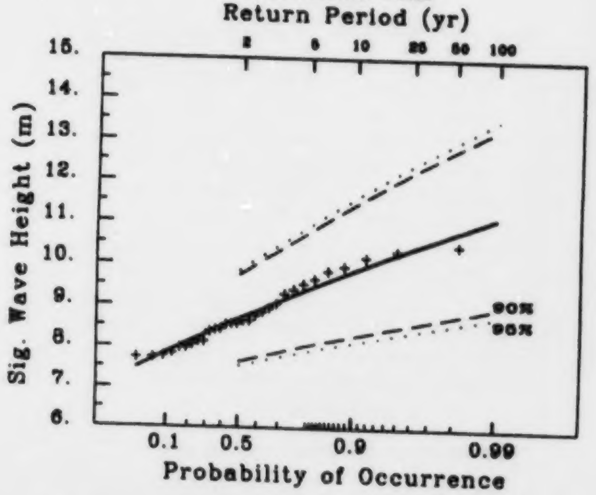


Figure 7.3 Gumbel vs. Borgman - Scotian Shelf

Grand Banks
Grid point 3744 – 46.88 N, 48.75 W

GUMBEL – Method of Moments

30 storms
Wave height threshold = 9.23 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Ho (m)
2	10.5	10.9	14.7	19.7	10.9
5	11.6	12.2	15.5	21.7	12.1
10	12.4	13.2	16.1	23.1	12.8
25	13.3	14.4	16.7	24.8	13.8
50	14.0	15.3	17.2	26.1	14.5
100	14.6	16.2	17.6	27.4	15.2

Tp, Hmax, and Hc were calculated using

$Tp = 4.046\ Hs^{0.548}$
$Hmax = 1.869\ Hs$
$Hc = 1.040\ Hs$

Grand Banks
Grid point 3744 – 46.88 N, 48.75 W

BORGMAN – Method of Moments

30 storms
Wave height threshold = 9.23 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Ho (m)
2	10.6	11.8	14.8	19.8	11.0
5	11.7	13.3	15.6	21.9	12.2
10	12.4	14.2	16.1	23.1	12.9
25	13.2	15.3	16.6	24.6	13.7
50	13.7	16.1	17.0	25.7	14.3
100	14.3	16.8	17.4	26.7	14.9

Tp, Hmax, and Hc were calculated using

$Tp = 4.046\ Hs^{0.548}$
$Hmax = 1.869\ Hs$
$Hc = 1.040\ Hs$

Correlation = 0.98

Correlation = 0.98

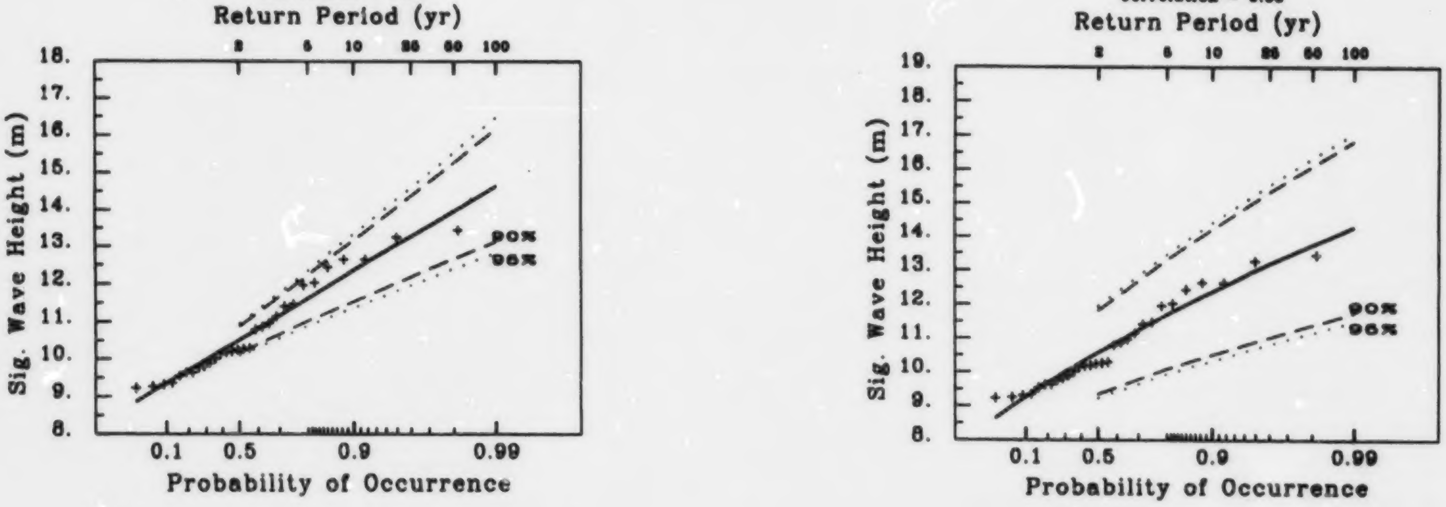


Figure 7.4 Gumbel vs. Borgman - Grand Banks

Table 7.1 Effect of Population Thresholds on Extreme Analysis

Georges Bank

Grid point 3498 - 41.88 N, 66.25 W

RETURN PERIOD	Hs > 6.96 m N = 30 BEST FIT	90% U.L.	Hs > 7.50 N = 21 BEST FIT	90% U.L.	Hs > 6.00 m N = 45 BEST FIT	90% U.L.
2 yr	7.9	8.2	7.9	8.2	7.8	8.0
5 yr	8.7	9.2	8.8	9.3	8.7	9.1
10 yr	9.3	9.8	9.3	9.9	9.3	9.8
25 yr	9.9	10.7	9.9	10.8	10.1	10.8
50 yr	10.4	11.4	10.4	11.4	10.6	11.5
100 yr	10.9	12.1	10.8	12.1	11.2	12.3

Soctian Shelf

Grid point 3590 - 43.75 N, 60.00 W

RETURN PERIOD	Hs > 7.72 m N = 30 BEST FIT	90% U.L.	Hs > 8.0 m N = 24 BEST FIT	90% U.L.	Hs > 7.0 m N = 46 BEST FIT	90% U.L.
2 yr	8.7	8.9	8.7	9.0	8.6	8.8
5 yr	9.4	9.8	9.4	9.8	9.3	9.7
10 yr	9.9	10.4	9.9	10.4	9.9	10.4
25 yr	10.5	11.2	10.4	11.1	10.6	11.2
50 yr	10.9	11.8	10.8	11.7	11.1	11.9
100 yr	11.4	12.4	11.2	12.2	11.6	12.5

Grand Banks

Grid point 3744 - 46.88 N, 48.75 W

RETURN PERIOD	Hs > 9.23 m N = 30 BEST FIT	90% U.L.	Hs >10.0 m N = 20 BEST FIT	90% U.L.	Hs > 8.0 m N = 41 BEST FIT	90% U.L.
2 yr	10.5	10.9	10.5	10.9	10.4	10.8
5 yr	11.6	12.2	11.7	12.4	11.6	12.1
10 yr	12.4	13.2	12.4	13.3	12.4	13.1
25 yr	13.3	14.4	13.2	14.4	13.4	14.4
50 yr	14.0	15.3	13.9	15.3	14.2	15.4
100 yr	14.6	16.2	14.5	16.1	14.9	16.4

7.4.3 Extreme Analysis Stratified by Direction

The 68 storm population at each of the three grid points was stratified by wave direction as shown in Figure 7.5. As shown, the given size of storm population is not sufficient to provide a full directional extreme analysis (i.e. 4-8 directional sectors). In order to obtain a reasonable subpopulations with sufficient size for the extremal analysis, only two broad directional sectors (90° width) were used at each site as follows:

- Georges Bank:	W (waves from SW to NW)
	N (waves from NW to NE)
- Scotian Shelf/Grand Banks:	SW (waves from S to W)
	NW (waves from W to N)

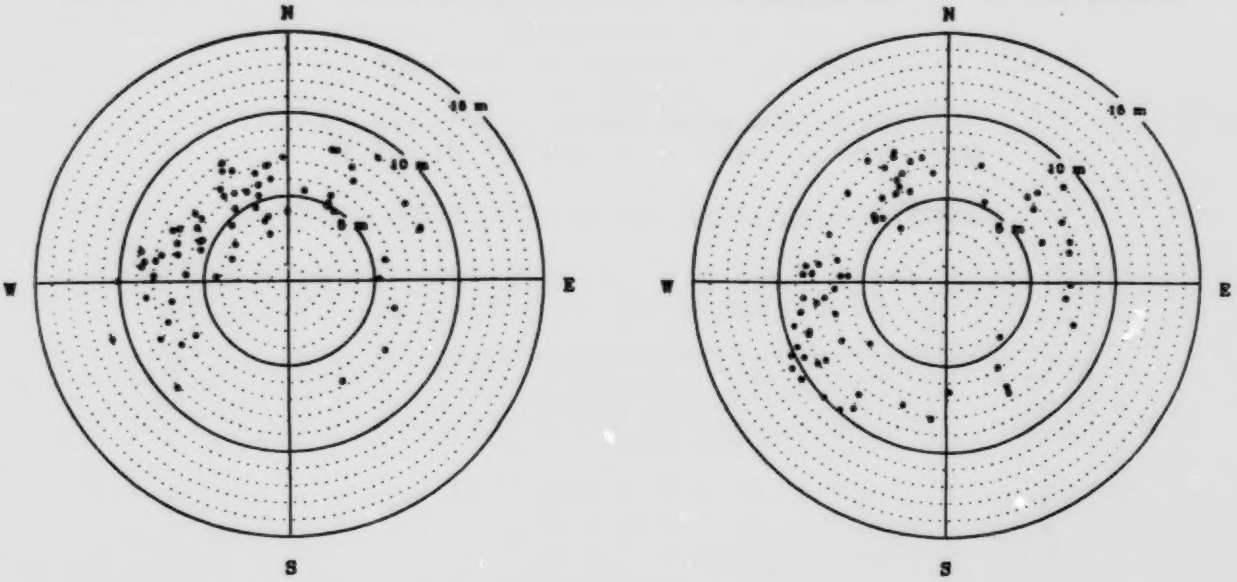
Three different thresholds were applied to each subset as shown in Tables 7.2, 7.3 and 7.4 for EB, SS and GB locations, respectively.

When compared with the results from the omni directional population, the directional subpopulations provided larger extreme wave heights at higher return period (i.e. 50-100 years) for the "primary" direction sector, and lower values at the other direction. It was also found that the results are more sensitive to the threshold values (about 10% difference) than that obtained from the omni-direction population. The results of this sensitivity analysis are shown below for 100 year return period wave heights.

	Omni-Direction	Directional Extremes	
	Top 30 Storms	Primary Direction	Secondary Direction
EB	$H_s > 7.0$ m	$H_s > 6.0$ m	$H_s > 5.5$ m
100 yr. H_s(m)	10.9	11.4	9.5
SS	$H_s > 7.7$ m	$H_s > 7.0$ m	$H_s > 6.0$ m
100 yr. H_s	11.4	11.8	9.7
GB	$H_s > 9.2$ m	$H_s > 8.0$ m	$H_s > 6.5$ m
100 yr. H_s	14.6	14.6	14.3

DISTRIBUTION OF STORM WAVE HEIGHTS

BY DIRECTION



Georges Bank

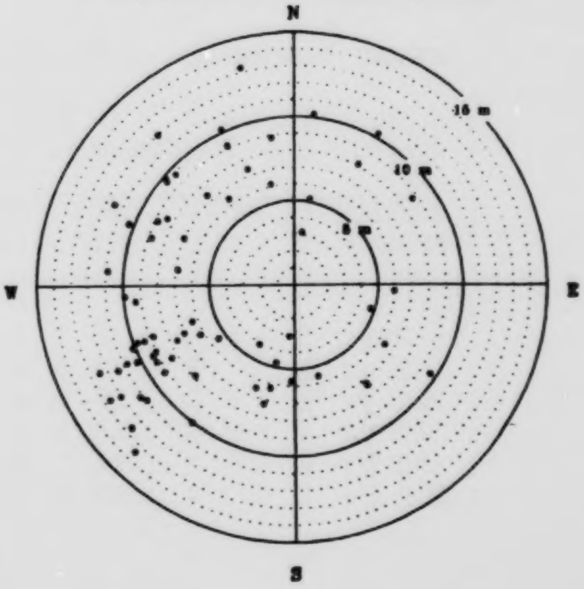
Grid point 3498 - 41.88 N, 66.25 W

Scotian Shelf

Grid point 3590 - 43.75 N, 60.00 W

Grand Banks

Grid point 3744 - 46.88 N, 48.75 W



Total = 68 Storms

(waves coming from)

Figure 7.5

Table 7.3

DIRECTIONAL EXTREME ANALYSIS

GUMBEL - Method of Moments

Georges Bank
Grid point 3498 - 41.88 N, 66.25 W

WAVES COMING FROM SW-NW CENTERED ON W

	Hs > 3.60 m 30 storms		Hs > 6.0 m 23 storms		Hs > 6.5 m 19 storms	
RETURN PERIOD	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)
2 yr	6.8	7.3	7.1	7.6	7.2	7.6
5 yr	8.3	9.1	8.4	9.1	8.4	9.1
10 yr	9.3	10.5	9.1	10.1	9.1	10.1
25 yr	10.6	12.1	10.1	11.3	10.0	11.3
50 yr	11.6	13.4	10.8	12.3	10.6	12.2
100 yr	12.5	14.6	11.4	13.2	11.3	13.1

WAVES COMING FROM NW-NE CENTERED ON N

	Hs > 3.70 m 30 storms		Hs > 5.0 m 23 storms		Hs > 5.50 m 19 storms	
RETURN PERIOD	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)
2 yr	6.0	6.3	6.2	6.5	6.3	6.6
5 yr	7.2	7.8	7.2	7.8	7.3	7.8
10 yr	8.0	8.8	7.9	8.7	7.9	8.6
25 yr	9.0	10.1	8.7	9.7	8.5	9.6
50 yr	9.7	11.1	9.2	10.5	9.0	10.3
100 yr	10.4	12.1	9.8	11.3	9.5	11.0

Table 7.8

DIRECTIONAL EXTREME ANALYSIS

GUMBEL - Method of Moments

Scotian Shelf
Grid point 3590 - 43.75 N, 60.00 W

WAVES COMING FROM S-W CENTERED ON SW

	Hs > 5.8 m 24 storms		Hs > 6.5 m 23 storms		Hs > 7.0 m 21 storms	
RETURN PERIOD	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)
2 yr	8.1	8.5	8.2	8.6	8.3	8.7
5 yr	9.3	10.0	9.3	9.9	9.3	9.9
10 yr	10.0	11.0	10.0	10.8	9.9	10.7
25 yr	11.0	12.2	10.8	12.0	10.7	11.7
50 yr	11.7	13.2	11.4	12.8	11.2	12.5
100 yr	12.4	14.1	12.1	13.6	11.8	13.2

WAVES COMING FROM W-N CENTERED ON NW

	Hs > 4.2 m 27 storms		Hs > 5.0 m 26 storms		Hs > 6.0 m 21 storms	
RETURN PERIOD	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)
2 yr	6.7	7.0	6.8	7.1	6.9	7.2
5 yr	7.7	8.3	7.7	8.2	7.8	8.2
10 yr	8.4	9.1	8.3	9.0	8.2	8.9
25 yr	9.2	10.2	9.0	10.0	8.9	9.7
50 yr	9.8	11.0	9.6	10.7	9.3	10.3
100 yr	10.4	11.8	10.1	11.4	9.7	10.9

Table 7.4

DIRECTIONAL EXTREME ANALYSIS

GUMBEL - Method of Moments

Grand Banks
Grid point 3744 - 46.88 N, 48.75 W

WAVES COMING FROM S-W CENTERED ON SW

RETURN PERIOD	Hs > 6.0 m 30 storms		Hs > 7.0 m 26 storms		Hs > 8.0 m 22 storms	
	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)
2 yr	9.2	9.7	9.4	9.9	9.7	10.1
5 yr	11.0	11.9	11.0	11.9	11.1	11.9
10 yr	12.2	13.5	12.0	13.2	12.0	13.0
25 yr	13.7	15.5	13.3	14.9	13.0	14.5
50 yr	14.8	16.9	14.3	16.2	13.8	15.6
100 yr	15.9	18.4	15.2	17.5	14.6	16.7

WAVES COMING FROM W-N CENTERED ON NW

RETURN PERIOD	Hs > 6.0 m 21 storms		Hs > 6.30 m 20 storms		Hs > 6.5 m 19 storms	
	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)	BEST FIT (m)	90% U.L (m)
2 yr	8.0	8.6	8.0	8.7	8.1	8.7
5 yr	9.9	11.0	10.0	11.0	10.0	11.1
10 yr	11.1	12.6	11.1	12.5	11.1	12.5
25 yr	12.5	14.5	12.4	14.4	12.4	14.3
50 yr	13.6	16.0	13.4	15.8	13.3	15.6
100 yr	14.6	17.4	14.4	17.2	14.3	17.0

7.5 FINAL RESULT

The extremal analysis was carried out at each grid point in the study domain (i.e. 118 sites) using the top 30 storms (out of the 68 events) without discrimination to their location, i.e. a different storm population was selected for each grid point. It should be noted that for the Georges Bank, only the extratropical storm population was considered in the analysis.

Extremes of significant wave height (H_s) and corresponding wind speed (W_s) extremes for risk factors from 0.5 to 0.01 (i.e. return period from 2 to 100 years) for all grid points in the study area are provided in Tables 7.5, 7.6 and 7.7 for EB, SS and GB, respectively. For the Georges Bank area, the 100 year extreme significant wave height varied between 10.1 and 11.3 m, with the corresponding wind speed ranges from 28.7 to 31.8 m/s. For the Scotian Shelf, the 100 year significant wave height varied between 9.3 to 11.7 m and the corresponding winds varied between 27.9 to 32.7 m/s. For the Grand Banks, the 100 year waves varied between 10.7 and 15.2 m and the corresponding winds ranged from 28.6 to 33.6 m/s.

The results of the detailed analysis carried out at the selected 25 grid points (Figure 7.1) are presented in Appendix D. It includes the H_s, H_{max}, H_c and T_p versus risk, the relation between T_p, and H_s, H_{max}/H_s and H_c/H_s ratios, and plot of H_s versus risk with 90% and 95% confidence levels.

Contour presentations of the 50 and 100 year return period significant wave height, maximum wave height, and the corresponding wind speed are given in Figures 7.6-7.11.

Table 7.5

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

Georges Bank

Significant Wave Height

Risk Factor Return Period			.50 2 yr		0.20 5 yr		0.10 10 yr		0.04 25 yr		0.02 50 yr		0.01 100 yr	
Grid Point	Lat (N)	Long (W)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)
3438	40.625	68.750	7.7	8.0	8.5	8.9	9.0	9.6	9.6	10.4	10.1	11.0	10.6	11.7
3439	40.625	67.500	8.1	8.3	8.8	9.1	9.2	9.7	9.8	10.5	10.2	11.0	10.6	11.6
3440	40.625	66.250	8.4	8.6	9.1	9.5	9.6	10.1	10.2	10.9	10.6	11.4	11.0	12.0
3467	41.250	68.750	7.5	7.7	8.3	8.7	8.8	9.3	9.4	10.2	9.9	10.8	10.4	11.4
3468	41.250	67.500	7.8	8.1	8.5	8.9	9.0	9.5	9.6	10.3	10.1	10.9	10.5	11.5
3469	41.250	66.250	8.2	8.4	8.9	9.3	9.4	9.9	10.0	10.7	10.4	11.3	10.9	11.8
3496	41.875	68.750	7.2	7.5	8.0	8.4	8.5	9.1	9.1	9.9	9.6	10.5	10.1	11.1
3497	41.875	67.500	7.6	7.8	8.4	8.8	8.9	9.5	9.5	10.3	10.0	11.0	10.5	11.6
3498	41.875	66.250	7.9	8.2	8.7	9.2	9.3	9.8	9.9	10.7	10.4	11.4	10.9	12.1
3499	41.875	65.000	8.2	8.5	9.1	9.5	9.6	10.2	10.3	11.1	10.8	11.8	11.3	12.5
3525	42.500	68.750	6.9	7.2	7.8	8.2	8.3	9.0	9.1	9.9	9.6	10.6	10.1	11.3
3526	42.500	67.500	7.4	7.7	8.2	8.7	8.8	9.4	9.5	10.3	10.0	11.0	10.5	11.7
3527	42.500	66.250	7.7	8.0	8.6	9.0	9.1	9.7	9.8	10.6	10.3	11.3	10.8	12.0
3555	43.125	67.500	7.1	7.4	8.0	8.5	8.6	9.3	9.4	10.3	9.9	11.0	10.5	11.8
3556	43.125	66.250	7.5	7.8	8.4	8.9	9.0	9.7	9.8	10.7	10.3	11.4	10.9	12.1
3585	43.750	66.250	7.0	7.3	8.0	8.6	8.7	9.4	9.5	10.5	10.1	11.3	10.7	12.1

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

Georges Bank

Maximum Wind Speeds Corresponding to Peak Significant Wave Height

Risk Factor Return Period			.50 2 yr		0.20 5 yr		0.10 10 yr		0.04 25 yr		0.02 50 yr		0.01 100 yr	
Grid Point	Lat (N)	Long (W)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)
3438	40.625	68.750	24.3	24.9	26.3	27.4	27.6	29.0	29.2	31.2	30.5	32.8	31.7	34.4
3439	40.625	67.500	24.1	24.5	25.3	26.0	26.2	27.1	27.2	28.4	28.0	29.4	28.7	30.4
3440	40.625	66.250	23.8	24.3	25.3	26.1	26.3	27.3	27.5	28.9	28.4	30.1	29.3	31.3
3467	41.250	68.750	24.1	24.7	26.1	27.1	27.4	28.8	29.0	30.9	30.2	32.5	31.4	34.1
3468	41.250	67.500	23.9	24.3	25.2	25.9	26.1	27.1	27.2	28.6	28.1	29.7	28.9	30.7
3469	41.250	66.250	23.8	24.2	25.1	25.8	26.0	26.9	27.1	28.4	27.9	29.4	28.7	30.5
3496	41.875	68.750	24.4	24.9	25.9	26.8	26.9	28.1	28.2	29.7	29.2	31.0	30.1	32.2
3497	41.875	67.500	24.2	24.7	25.7	26.5	26.7	27.9	28.0	29.5	29.0	30.8	29.9	32.0
3498	41.875	66.250	24.2	24.6	25.6	26.4	26.6	27.6	27.8	29.2	28.6	30.3	29.5	31.5
3499	41.875	65.000	24.0	24.4	25.2	25.8	26.0	26.8	26.9	28.1	27.7	29.0	28.4	30.0
3525	42.500	68.750	24.3	24.9	26.1	27.1	27.4	28.7	28.9	30.7	30.0	32.2	31.1	33.7
3526	42.500	67.500	24.1	24.6	25.8	26.8	27.0	28.3	28.5	30.3	29.6	31.7	30.7	33.2
3527	42.500	66.250	24.3	24.7	25.6	26.4	26.5	27.5	27.6	28.9	28.5	30.0	29.3	31.1
3555	43.125	67.500	24.0	24.6	26.0	27.0	27.3	28.7	29.0	30.9	30.2	32.6	31.4	34.2
3556	43.125	66.250	24.2	24.8	26.2	27.3	27.6	29.1	29.3	31.3	30.5	32.9	31.8	34.6
3585	43.750	66.250	24.2	24.8	26.0	27.0	27.2	28.5	28.7	30.5	29.8	32.0	31.0	33.4

Table 7.6

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

Scotian Shelf

Significant Wave Height

Risk Factor Return Period			.50 2 yr		0.20 5 yr		0.10 10 yr		0.04 25 yr		0.02 50 yr		0.01 100 yr	
Grid Point	Lat (N)	Long (W)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)
3528	42.500	65.000	8.0	8.3	8.9	9.4	9.5	10.2	10.3	11.1	10.8	11.9	11.4	12.6
3529	42.500	63.750	8.3	8.6	9.2	9.7	9.8	10.4	10.5	11.4	11.1	12.1	11.6	12.8
3530	42.500	62.500	8.6	8.8	9.4	9.8	9.9	10.5	10.6	11.3	11.1	12.0	11.5	12.6
3557	43.125	65.000	7.8	8.1	8.7	9.2	9.3	10.0	10.1	11.1	10.7	11.8	11.3	12.6
3558	43.125	63.750	8.1	8.4	9.0	9.5	9.7	10.4	10.5	11.4	11.0	12.2	11.6	13.0
3559	43.125	62.500	8.3	8.6	9.2	9.7	9.8	10.5	10.6	11.4	11.1	12.2	11.7	12.9
3560	43.125	61.250	8.6	8.9	9.4	9.8	9.8	10.4	10.5	11.2	10.9	11.8	11.4	12.4
3561	43.125	60.000	8.9	9.1	9.5	9.9	10.0	10.4	10.5	11.1	10.9	11.7	11.3	12.2
3586	43.750	65.000	7.3	7.7	8.4	8.9	9.1	9.8	9.9	11.0	10.6	11.8	11.2	12.7
3587	43.750	63.750	7.7	8.0	8.7	9.3	9.4	10.2	10.3	11.3	10.9	12.1	11.6	13.0
3588	43.750	62.500	8.0	8.3	9.0	9.5	9.6	10.3	10.4	11.4	11.0	12.2	11.6	13.0
3589	43.750	61.250	8.3	8.6	9.2	9.6	9.7	10.4	10.5	11.3	11.0	12.0	11.5	12.7
3590	43.750	60.000	8.7	8.9	9.4	9.8	9.9	10.4	10.5	11.2	10.9	11.8	11.4	12.4
3591	43.750	58.750	9.0	9.2	9.6	9.9	10.0	10.4	10.5	11.1	10.9	11.6	11.3	12.1
3592	43.750	57.500	9.2	9.4	9.8	10.1	10.2	10.6	10.6	11.1	10.9	11.6	11.3	12.0
3616	44.375	63.750	6.8	7.2	7.9	8.4	8.6	9.3	9.4	10.5	10.1	11.3	10.7	12.1
3617	44.375	62.500	7.4	7.7	8.5	9.0	9.1	9.9	10.0	11.1	10.7	11.9	11.3	12.7
3618	44.375	61.250	7.9	8.2	8.8	9.3	9.4	10.1	10.2	11.2	10.8	11.9	11.4	12.7
3619	44.375	60.000	8.4	8.6	9.1	9.5	9.6	10.2	10.3	11.0	10.7	11.6	11.2	12.2
3620	44.375	58.750	8.7	9.0	9.4	9.8	9.9	10.4	10.4	11.1	10.8	11.6	11.3	12.2
3621	44.375	57.500	9.0	9.2	9.6	10.0	10.0	10.5	10.6	11.2	10.9	11.7	11.3	12.2
3647	45.000	61.250	7.4	7.7	8.4	9.0	9.1	9.9	10.0	11.0	10.7	11.9	11.3	12.7
3648	45.000	60.000	8.2	8.4	8.9	9.3	9.4	9.9	10.0	10.7	10.5	11.3	10.9	11.9
3649	45.000	58.750	8.5	8.8	9.2	9.6	9.7	10.2	10.2	10.9	10.7	11.5	11.1	12.0
3650	45.000	57.500	8.8	9.0	9.5	9.8	9.9	10.4	10.5	11.1	10.9	11.7	11.3	12.2
3677	45.625	60.000	7.7	7.9	8.3	8.7	8.7	9.2	9.3	9.9	9.7	10.4	10.1	11.0
3678	45.625	58.750	8.1	8.4	8.9	9.3	9.4	9.9	10.0	10.7	10.4	11.3	10.9	11.9
3679	45.625	57.500	8.5	8.7	9.2	9.6	9.7	10.2	10.3	11.0	10.7	11.6	11.2	12.2
3706	46.250	60.000	7.3	7.5	7.8	8.1	8.2	8.6	8.6	9.2	9.0	9.6	9.3	10.1
3707	46.250	58.750	7.8	8.0	8.5	8.9	9.0	9.6	9.6	10.3	10.1	10.9	10.5	11.5
3736	46.875	58.750	7.3	7.6	8.0	8.4	8.5	9.1	9.1	9.9	9.6	10.4	10.0	11.0

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

Scotian Shelf

Maximum Wind Speeds Corresponding to Peak Significant Wave Height

Risk Factor Return Period			.50 2 yr		0.20 5 yr		0.10 10 yr		0.04 25 yr		0.02 50 yr		0.01 100 yr	
Grid Point	Lat (N)	Long (W)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)
3528	42.500	65.000	24.0	24.3	25.2	25.8	25.9	26.8	26.9	28.1	27.7	29.1	28.4	30.1
3529	42.500	63.750	24.4	24.7	25.4	26.0	26.2	27.0	27.1	28.1	27.7	29.0	28.4	29.9
3530	42.500	62.500	24.1	24.4	25.1	25.7	25.8	26.5	26.6	27.6	27.3	28.5	27.9	29.3
3557	43.125	65.000	24.0	24.5	25.6	26.6	26.8	28.0	28.2	29.8	29.2	31.2	30.2	32.6
3558	43.125	63.750	24.3	24.8	25.8	26.7	26.9	28.0	28.2	29.7	29.1	30.9	30.1	32.2
3559	43.125	62.500	24.1	24.5	25.4	26.0	26.2	27.1	27.2	28.4	27.9	29.4	28.7	30.4
3560	43.125	61.250	24.1	24.6	25.6	26.4	26.6	27.7	27.9	29.3	28.8	30.6	29.7	31.8
3561	43.125	60.000	24.4	24.9	26.0	26.8	27.0	28.1	28.3	29.9	29.3	31.1	30.3	32.4
3586	43.750	65.000	24.3	24.8	26.0	27.0	27.2	28.5	28.7	30.4	29.8	31.8	30.8	33.3
3587	43.750	63.750	24.3	24.9	26.2	27.3	27.5	28.9	29.1	31.0	30.3	32.6	31.5	34.2
3588	43.750	62.500	24.1	24.5	25.5	26.2	26.4	27.4	27.5	28.9	28.4	30.0	29.2	31.1
3589	43.750	61.250	24.4	24.9	26.1	26.9	27.1	28.3	28.5	30.1	29.5	31.4	30.5	32.7
3590	43.750	60.000	24.2	24.6	25.4	26.1	26.2	27.1	27.3	28.5	28.0	29.5	28.8	30.5
3591	43.750	58.750	24.1	24.7	25.8	26.7	26.9	28.2	28.3	30.0	29.4	31.4	30.4	32.8
3592	43.750	57.500	24.2	24.7	25.7	26.5	26.7	27.8	28.0	29.4	28.9	30.6	29.8	31.8
3616	44.375	63.750	24.1	24.9	26.4	27.7	28.0	29.6	29.9	32.2	31.3	34.0	32.7	35.9
3617	44.375	62.500	23.7	24.3	25.4	26.3	26.5	27.7	27.8	29.5	28.8	30.8	29.9	32.1
3618	44.375	61.250	24.3	24.8	25.8	26.7	26.9	28.0	28.1	29.6	29.1	30.9	30.0	32.1
3619	44.375	60.000	24.4	24.8	25.6	26.2	26.4	27.2	27.3	28.5	28.1	29.5	28.8	30.4
3620	44.375	58.750	24.4	24.8	25.6	26.3	26.4	27.3	27.4	28.7	28.2	29.7	29.0	30.7
3621	44.375	57.500	24.3	24.8	25.8	26.7	26.8	28.0	28.1	29.7	29.1	30.9	30.1	32.2
3647	45.000	61.250	23.7	24.1	25.1	25.8	26.0	27.0	27.2	28.5	28.0	29.7	28.9	30.8
3648	45.000	60.000	24.0	24.4	25.2	25.9	26.0	26.9	27.0	28.3	27.8	29.3	28.6	30.2
3649	45.000	58.750	23.9	24.3	25.1	25.7	25.9	26.7	26.9	28.0	27.6	29.0	28.3	29.9
3650	45.000	57.500	24.2	24.6	25.6	26.3	26.5	27.5	27.7	29.0	28.5	30.2	29.4	31.3
3677	45.625	60.000	23.6	24.0	24.9	25.7	25.8	26.8	27.0	28.3	27.8	29.4	28.7	30.5
3678	45.625	58.750	23.9	24.3	25.3	26.0	26.2	27.2	27.3	28.7	28.2	29.8	29.0	30.9
3679	45.625	57.500	24.2	24.6	25.5	26.2	26.4	27.4	27.5	28.8	28.3	29.9	29.1	30.9
3706	46.250	60.000	23.4	23.9	24.9	25.7	25.9	27.0	27.2	28.6	28.1	29.9	29.8	31.1
3707	46.250	58.750	23.5	24.0	24.8	25.5	25.7	26.6	26.7	28.0	27.5	29.0	28.3	30.0
3736	46.875	58.750	23.3	23.8	24.7	25.5	25.7	26.7	26.9	28.3	27.7	29.4	28.6	30.6

Table 7.7

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

Grand Banks

Significant Wave Height

Risk Factor Return Period			.50 2 yr		0.20 5 yr		0.10 10 yr		0.04 25 yr		0.02 50 yr		0.01 100 yr	
Grid Point	Lat (N)	Long (W)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)	Best Fit (m)	90% U.L. (m)
3568	43.125	51.250	10.1	10.4	11.0	11.5	11.6	12.3	12.4	13.3	13.0	14.1	13.6	14.8
3569	43.125	50.000	10.2	10.6	11.2	11.8	11.9	12.6	12.7	13.7	13.3	14.5	13.9	15.3
3596	43.750	52.500	9.8	10.1	10.7	11.1	11.2	11.8	11.9	12.7	12.4	13.4	13.0	14.1
3597	43.750	51.250	10.1	10.3	11.0	11.5	11.6	12.2	12.3	13.2	12.9	14.0	13.5	14.7
3598	43.750	50.000	10.3	10.6	11.3	11.8	12.0	12.7	12.8	13.8	13.4	14.6	14.0	15.4
3624	44.375	53.750	9.6	9.9	10.4	10.8	10.9	11.4	11.5	12.2	12.0	12.8	12.4	13.4
3625	44.375	52.500	9.9	10.1	10.7	11.1	11.2	11.8	11.9	12.6	12.3	13.3	12.8	13.9
3626	44.375	51.250	10.1	10.4	10.9	11.4	11.5	12.1	12.2	13.1	12.8	13.8	13.3	14.5
3627	44.375	50.000	10.3	10.6	11.3	11.8	12.0	12.7	12.8	13.8	13.4	14.6	14.1	15.5
3628	44.375	48.750	10.5	10.8	11.6	12.2	12.3	13.2	13.3	14.4	14.0	15.3	14.7	16.2
3651	45.000	56.250	9.0	9.3	9.7	10.1	10.2	10.7	10.7	11.4	11.2	12.0	11.6	12.5
3652	45.000	55.000	9.3	9.5	10.0	10.3	10.4	10.9	10.9	11.6	11.4	12.1	11.8	12.7
3653	45.000	53.750	9.5	9.8	10.3	10.7	10.8	11.4	11.5	12.2	11.9	12.8	12.4	13.5
3654	45.000	52.500	9.9	10.1	10.6	11.1	11.2	11.8	11.8	12.6	12.3	13.3	12.8	13.9
3655	45.000	51.250	10.1	10.4	11.0	11.4	11.5	12.2	12.3	13.1	12.8	13.8	13.3	14.5
3656	45.000	50.000	10.3	10.7	11.3	11.9	12.0	12.7	12.8	13.8	13.5	14.7	14.1	15.5
3657	45.000	48.750	10.5	10.9	11.6	12.2	12.3	13.2	13.3	14.4	14.0	15.3	14.6	16.1
3680	45.625	56.250	8.8	9.1	9.6	9.9	10.0	10.6	10.6	11.3	11.1	11.9	11.5	12.5
3681	45.625	55.000	9.1	9.4	9.9	10.3	10.3	10.9	11.0	11.7	11.4	12.3	11.9	12.9
3682	45.625	53.750	9.4	9.7	10.2	10.7	10.8	11.4	11.5	12.3	12.0	12.9	12.5	13.6
3683	45.625	52.500	9.9	10.1	10.7	11.1	11.2	11.8	11.9	12.7	12.4	13.4	12.9	14.0
3684	45.625	51.250	10.2	10.5	11.0	11.5	11.6	12.2	12.3	13.1	12.8	13.8	13.3	14.5
3685	45.625	50.000	10.4	10.7	11.3	11.9	12.0	12.7	12.8	13.8	13.4	14.5	14.0	15.3
3686	45.625	48.750	10.6	10.9	11.7	12.2	12.4	13.2	13.3	14.4	14.0	15.3	14.6	16.2
3687	45.625	47.500	10.7	11.1	11.8	12.5	12.6	13.4	13.6	14.7	14.3	15.6	15.0	16.5
3708	46.250	57.500	8.2	8.5	9.0	9.4	9.5	10.1	10.2	11.0	10.7	11.6	11.1	12.2
3709	46.250	56.250	8.5	8.8	9.3	9.7	9.8	10.4	10.5	11.3	11.0	12.0	11.5	12.6
3710	46.250	55.000	8.9	9.1	9.6	10.1	10.2	10.7	10.8	11.6	11.3	12.2	11.7	12.8
3711	46.250	53.750	9.2	9.5	10.1	10.5	10.6	11.2	11.3	12.2	11.9	12.9	12.4	13.5
3712	46.250	52.500	9.8	10.0	10.5	10.9	11.0	11.6	11.7	12.4	12.2	13.1	12.6	13.7
3713	46.250	51.250	10.1	10.4	11.0	11.5	11.6	12.2	12.3	13.1	12.8	13.8	13.3	14.5
3714	46.250	50.000	10.4	10.7	11.3	11.9	12.0	12.7	12.8	13.7	13.4	14.5	13.9	15.3
3715	46.250	48.750	10.6	10.9	11.7	12.2	12.4	13.2	13.3	14.3	13.9	15.2	14.6	16.1
3716	46.250	47.500	10.8	11.1	11.9	12.5	12.7	13.5	13.6	14.7	14.3	15.6	15.0	16.6
3717	46.250	46.250	10.8	11.2	11.9	12.5	12.6	13.4	13.5	14.6	14.2	15.5	14.9	16.3
3737	46.875	57.500	7.8	8.0	8.6	9.0	9.1	9.6	9.7	10.5	10.2	11.1	10.7	11.8
3738	46.875	56.250	8.1	8.3	8.9	9.4	9.5	10.1	10.2	11.0	10.7	11.7	11.2	12.3
3739	46.875	55.000	8.4	8.7	9.3	9.7	9.8	10.5	10.6	11.5	11.1	12.2	11.7	12.9
3740	46.875	53.750	8.7	9.1	9.7	10.2	10.3	11.0	11.1	12.1	11.7	12.8	12.3	13.6
3741	46.875	52.500	9.7	9.9	10.5	10.9	11.0	11.6	11.7	12.4	12.1	13.1	12.6	13.7
3742	46.875	51.250	9.9	10.1	10.7	11.1	11.2	11.8	11.9	12.7	12.4	13.3	12.9	14.0
3743	46.875	50.000	10.3	10.6	11.3	11.8	12.0	12.7	12.8	13.8	13.4	14.6	14.0	15.4
3744	46.875	48.750	10.5	10.9	11.6	12.2	12.4	13.2	13.3	14.4	14.0	15.3	14.6	16.2
3745	46.875	47.500	10.7	11.1	11.9	12.5	12.6	13.5	13.6	14.7	14.3	15.7	15.0	16.6
3746	46.875	46.250	10.8	11.2	11.9	12.5	12.7	13.5	13.6	14.7	14.3	15.6	14.9	16.5
3770	47.500	52.500	8.9	9.1	9.6	10.1	10.1	10.7	10.8	11.5	11.2	12.1	11.7	12.8
3771	47.500	51.250	9.6	9.9	10.4	10.9	11.0	11.6	11.6	12.4	12.2	13.1	12.7	13.8
3772	47.500	50.000	10.0	10.3	11.0	11.5	11.6	12.3	12.4	13.3	12.9	14.0	13.5	14.8
3773	47.500	48.750	10.3	10.7	11.4	12.0	12.1	12.9	13.0	14.1	13.7	15.0	14.4	15.9
3774	47.500	47.500	10.5	10.9	11.7	12.4	12.6	13.5	13.6	14.8	14.4	15.8	15.1	16.8
3775	47.500	46.250	10.5	10.9	11.8	12.5	12.6	13.5	13.7	14.9	14.4	15.9	15.2	16.9
3799	48.125	52.500	8.5	8.8	9.4	9.9	10.0	10.6	10.7	11.6	11.3	12.3	11.8	13.1
3800	48.125	51.250	9.4	9.7	10.3	10.8	10.9	11.5	11.6	12.5	12.1	13.2	12.7	13.9
3801	48.125	50.000	9.8	10.1	10.7	11.2	11.3	12.0	12.1	13.0	12.6	13.7	13.2	14.4
3802	48.125	48.750	10.1	10.4	11.1	11.6	11.8	12.5	12.6	13.6	13.2	14.4	13.8	15.2
3803	48.125	47.500	10.3	10.7	11.5	12.1	12.3	13.1	13.3	14.4	14.0	15.4	14.7	16.4
3804	48.125	46.250	10.4	10.8	11.7	12.4	12.5	13.5	13.6	14.9	14.4	15.9	15.2	17.0
3828	48.750	52.500	8.5	8.8	9.5	10.0	10.2	10.9	11.0	12.0	11.7	12.9	12.3	13.7
3829	48.750	51.250	9.2	9.5	10.1	10.6	10.7	11.4	11.5	12.4	12.1	13.2	12.6	13.9
3830	48.750	50.000	9.6	9.9	10.5	11.0	11.1	11.8	11.9	12.8	12.4	13.5	13.0	14.2
3831	48.750	48.750	9.9	10.2	10.8	11.3	11.5	12.1	12.2	13.1	12.8	13.9	13.4	14.6
3832	48.750	47.500	10.0	10.4	11.1	11.7	11.9	12.7	12.8	13.8	13.4	14.7	14.1	15.6
3833	48.750	46.250	10.1	10.5	11.4	12.1	12.2	13.2	13.3	14.5	14.1	15.6	14.9	16.6
3857	49.375	52.500	8.5	8.8	9.5	10.0	10.1	10.9	11.0	11.9	11.6	12.7	12.2	13.5
3858	49.375	51.250	9.1	9.4	10.0	10.6	10.7	11.4	11.5	12.4	12.1	13.2	12.7	14.0
3859	49.375	50.000	9.4	9.7	10.3	10.8	10.9	11.6	11.7	12.6	12.3	13.3	12.8	14.1
3860	49.375	48.750	9.6	9.9	10.6	11.1	11.2	11.9	12.0	13.0	12.6	13.8	13.2	14.6
3861	49.375	47.500	9.8	10.1	10.8	11.3	11.5	12.2	12.3	13.3	12.9	14.1	13.6	15.0
3886	50.000	52.500	8.5	8.8	9.5	10.0	10.1	10.9	11.0	11.9	11.6	12.7	12.2	13.5
3887	50.000	51.250	9.0	9.3	9.9	10.4	10.5	11.2	11.3	12.2	11.9	13.0	12.5	13.7
3888	50.000	50.000	9.3	9.6	10.2	10.7	10.8	11.4	11.5	12.4	12.1	13.2	12.7	13.9
3889	50.000	48.750	9.4	9.7	10.3	10.9	11.0	11.7	11.8	12.7	12.3	13.5	12.9	14.2

Table 7.7 (cont'd)

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

Grand Banks

Maximum Wind Speeds Corresponding to Peak Significant Wave Height

Risk Factor Return Period			.50 2 yr		0.20 5 yr		0.10 10 yr		0.04 25 yr		0.02 50 yr		0.01 100 yr	
Grid Point	Lat (N)	Long (W)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)	Best Fit (m/s)	90% U.L. (m/s)
3568	43.125	51.250	24.0	24.7	26.2	27.3	27.6	29.2	29.4	31.5	30.7	33.3	32.1	35.0
3569	43.125	50.000	23.8	24.5	26.1	27.3	27.6	29.3	29.5	31.8	31.0	33.7	32.4	35.6
3596	43.750	52.500	24.2	24.9	26.4	27.6	27.8	29.5	29.7	31.9	31.1	33.7	32.4	35.5
3597	43.750	51.250	24.0	24.7	26.3	27.5	27.8	29.5	29.7	32.0	31.1	33.8	32.5	35.7
3598	43.750	50.000	24.2	25.0	26.6	27.9	28.1	29.9	30.1	32.5	31.6	34.4	33.1	36.3
3624	44.375	53.750	24.6	25.2	26.4	27.3	27.6	28.8	29.0	30.8	30.1	32.2	31.2	33.6
3625	44.375	52.500	24.6	25.3	26.7	27.9	28.1	29.7	29.9	32.0	31.2	33.7	32.5	35.4
3626	44.375	51.250	24.3	25.1	26.6	27.9	28.1	29.8	30.0	32.3	31.4	34.1	32.8	36.0
3627	44.375	50.000	24.4	25.2	26.8	28.1	28.4	30.1	30.4	32.7	31.8	34.6	33.3	36.6
3628	44.375	48.750	24.1	24.9	26.5	27.9	28.1	29.9	30.2	32.6	31.7	34.6	33.2	36.6
3651	45.000	56.250	24.7	25.1	26.2	27.0	27.2	28.3	28.5	30.0	29.4	31.2	30.3	32.4
3652	45.000	55.000	24.8	25.2	26.2	26.9	27.0	28.0	28.2	29.5	29.0	30.6	29.8	31.7
3653	45.000	53.750	24.9	25.4	26.5	27.4	27.6	28.9	29.0	30.7	30.1	32.0	31.1	33.4
3654	45.000	52.500	24.8	25.4	26.7	27.7	28.0	29.4	29.6	31.5	30.8	33.1	32.0	34.7
3655	45.000	51.250	24.9	25.6	27.1	28.3	28.6	30.2	30.4	32.6	31.8	34.4	33.2	36.2
3656	45.000	50.000	24.6	25.4	27.0	28.3	28.6	30.4	30.6	33.0	32.1	35.0	33.6	37.0
3657	45.000	48.750	24.4	25.2	26.8	28.1	28.4	30.1	30.4	32.8	31.9	34.7	33.3	36.6
3680	45.625	56.250	24.9	25.3	26.2	27.0	27.1	28.1	28.3	29.6	29.1	30.7	29.9	31.8
3681	45.625	55.000	25.0	25.4	26.3	27.0	27.2	28.1	28.2	29.5	29.0	30.5	29.8	31.6
3682	45.625	53.750	24.9	25.4	26.5	27.4	27.6	28.8	28.9	30.5	29.9	31.8	30.9	33.1
3683	45.625	52.500	25.1	25.6	26.8	27.7	28.0	29.2	29.4	31.1	30.5	32.6	31.6	34.0
3684	45.625	51.250	25.0	25.6	26.9	27.9	28.1	29.5	29.7	31.6	30.9	33.1	32.1	34.7
3685	45.625	50.000	24.9	25.6	26.9	28.1	28.3	29.8	30.0	32.0	31.3	33.7	32.5	35.3
3686	45.625	48.750	24.8	25.5	27.0	28.1	28.4	29.9	30.1	32.2	31.5	34.0	32.8	35.7
3687	45.625	47.500	24.8	25.3	26.6	27.6	27.8	29.1	29.3	31.1	30.4	32.6	31.5	34.0
3708	46.250	57.500	24.4	24.8	25.5	26.2	26.3	27.1	27.2	28.4	27.9	29.3	28.6	30.2
3709	46.250	56.250	24.6	25.1	26.1	26.8	27.0	28.1	28.2	29.6	29.1	30.8	30.0	31.9
3710	46.250	55.000	24.9	25.3	26.2	26.9	27.1	28.1	28.2	29.5	29.0	30.6	29.9	31.7
3711	46.250	53.750	24.7	25.2	26.2	27.1	27.3	28.4	28.5	30.1	29.5	31.3	30.5	32.6
3712	46.250	52.500	24.9	25.4	26.5	27.4	27.6	28.7	28.9	30.5	29.9	31.8	30.9	33.2
3713	46.250	51.250	25.0	25.5	26.7	27.6	27.8	29.1	29.2	30.9	30.3	32.3	31.4	33.7
3714	46.250	50.000	25.2	25.7	26.9	27.8	28.0	29.3	29.4	31.1	30.5	32.5	31.5	33.9
3715	46.250	48.750	25.3	26.0	27.3	28.4	28.6	30.1	30.3	32.2	31.5	33.8	32.7	35.4
3716	46.250	47.500	25.2	25.8	27.0	28.0	28.2	29.6	29.8	31.6	30.9	33.1	32.0	34.6
3737	46.875	57.500	24.0	24.4	25.4	26.2	26.3	27.4	27.5	28.9	28.4	30.1	29.3	31.2
3738	46.875	56.250	24.4	24.9	25.9	26.7	26.9	28.0	28.2	29.7	29.1	30.9	30.0	32.1
3739	46.875	55.000	24.5	25.1	26.3	27.3	27.6	28.9	29.1	31.0	30.3	32.5	31.4	34.0
3740	46.875	53.750	24.9	25.3	26.3	27.1	27.3	28.4	28.5	30.0	29.4	31.1	30.3	32.3
3741	46.875	52.500	24.8	25.3	26.3	27.1	27.3	28.4	28.5	30.0	29.4	31.2	30.4	32.4
3742	46.875	51.250	24.9	25.3	26.4	27.2	27.3	28.4	28.6	30.0	29.5	31.3	30.4	32.5
3743	46.875	50.000	25.2	25.8	27.0	28.0	28.2	29.5	29.7	31.5	30.8	33.0	32.0	34.5
3744	46.875	48.750	25.6	26.3	27.7	28.8	29.1	30.6	30.8	32.8	32.1	34.5	33.4	36.2
3745	46.875	47.500	25.5	26.1	27.3	28.3	28.5	29.8	30.0	31.7	31.1	33.2	32.2	34.6
3746	46.875	46.250	25.0	25.5	26.6	27.5	27.7	28.9	29.0	30.6	30.0	32.0	31.0	33.3
3770	47.500	52.500	24.4	24.9	26.0	26.9	27.1	28.3	28.4	30.0	29.4	31.4	30.5	32.7
3771	47.500	51.250	24.8	25.4	26.5	27.5	27.7	28.9	29.1	30.8	30.1	32.1	31.2	33.5
3772	47.500	50.000	25.1	25.6	26.9	27.9	28.1	29.5	29.6	31.5	30.8	33.0	31.9	34.4
3773	47.500	48.750	25.5	26.1	27.4	28.4	28.6	30.0	30.2	32.1	31.4	33.6	32.6	35.2
3774	47.500	47.500	25.4	26.0	27.3	28.3	28.5	29.9	30.1	31.9	31.2	33.4	32.4	35.0
3775	47.500	46.250	24.7	25.3	26.4	27.3	27.5	28.8	29.0	30.6	30.0	32.0	31.1	33.4
3799	48.125	52.500	24.8	25.4	26.7	27.7	27.9	29.2	29.4	31.2	30.6	32.7	31.7	34.2
3800	48.125	51.250	24.9	25.5	26.9	28.0	28.3	29.8	30.0	32.0	31.2	33.7	32.5	35.3
3801	48.125	50.000	24.7	25.3	26.5	27.4	27.7	28.9	29.1	30.9	30.2	32.3	31.3	33.8
3802	48.125	48.750	24.8	25.5	26.8	27.9	28.2	29.7	29.9	31.9	31.2	33.6	32.4	35.3
3803	48.125	47.500	24.9	25.6	27.0	28.1	28.3	29.8	30.0	32.1	31.3	33.7	32.6	35.4
3804	48.125	46.250	24.4	25.0	26.2	27.1	27.3	28.6	28.8	30.5	29.9	32.0	31.0	33.4
3828	48.750	52.500	24.2	24.9	26.3	27.4	27.7	29.2	29.4	31.5	30.7	33.2	32.0	34.9
3829	48.750	51.250	24.7	25.4	26.6	27.7	27.9	29.3	29.5	31.3	30.6	32.9	31.8	34.4
3830	48.750	50.000	24.3	24.9	26.2	27.3	27.5	28.9	29.1	31.0	30.3	32.5	31.4	34.1
3831	48.750	48.750	24.4	25.1	26.6	27.8	28.1	29.7	29.9	32.1	31.3	33.9	32.7	35.7
3832	48.750	47.500	24.2	24.9	26.4	27.5	27.8	29.4	29.6	31.7	30.9	33.5	32.3	35.2
3833	48.750	46.250	24.0	24.7	26.1	27.2	27.5	29.0	29.2	31.3	30.5	33.0	31.8	34.7
3857	49.375	52.500	24.2	24.9	26.3	27.4	27.6	29.1	29.3	31.3	30.6	33.0	31.9	34.7
3858	49.375	51.250	24.3	25.0	26.4	27.5	27.8	29.3	29.5	31.5	30.8	33.2	32.0	34.9
3859	49.375	50.000	24.6	25.2	26.5	27.6	27.8	29.2	29.4	31.3	30.6	32.9	31.8	34.4
3860	49.375	48.750	23.9	24.6	26.1	27.2	27.5	29.0	29.2	31.3	30.5	33.1	31.9	34.8
3861	49.375	47.500	23.8	24.5	26.1	27.3	27.6	29.3	29.5	31.8	30.9	33.6	32.3	35.5
3886	50.000	52.500	23.6	24.4	25.9	27.2	27.5	29.1	29.4	31.6	30.8	33.5	32.2	35.4
3887	50.000	51.250	24.3	25.1	26.6	27.7	28.0	29.6	29.9	32.0	31.2	33.8	32.6	35.6
3888	50.000	50.000	24.3	24.9	26.2	27.3	27.5	29.0	29.2	31.1	30.4	32.7	31.6	34.3
3889	50.000	48.750	24.2	24.9	26.3	27.5	27.7	29.2	29.5	31.5	30.8	33.2	32.0	34.9

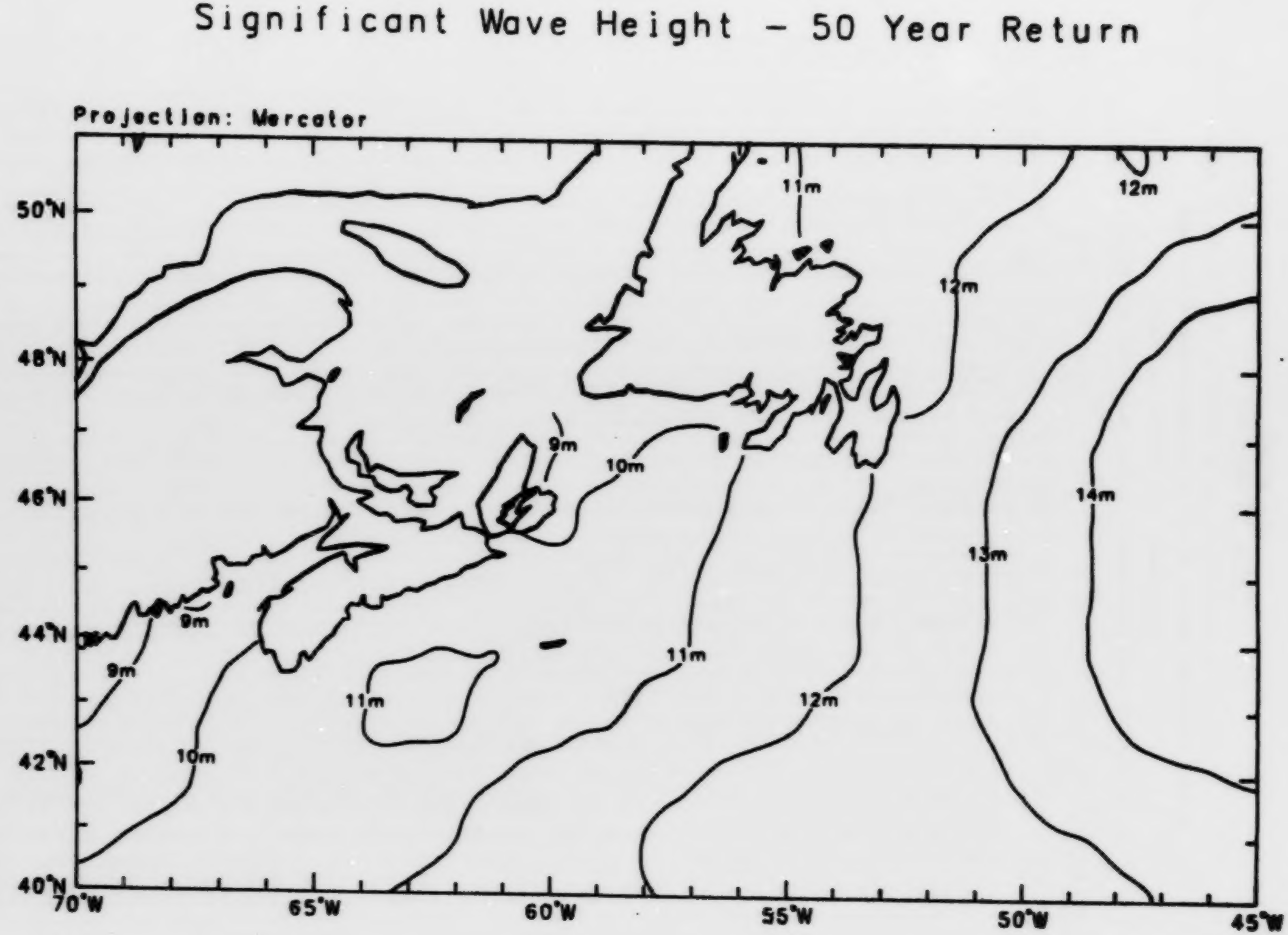
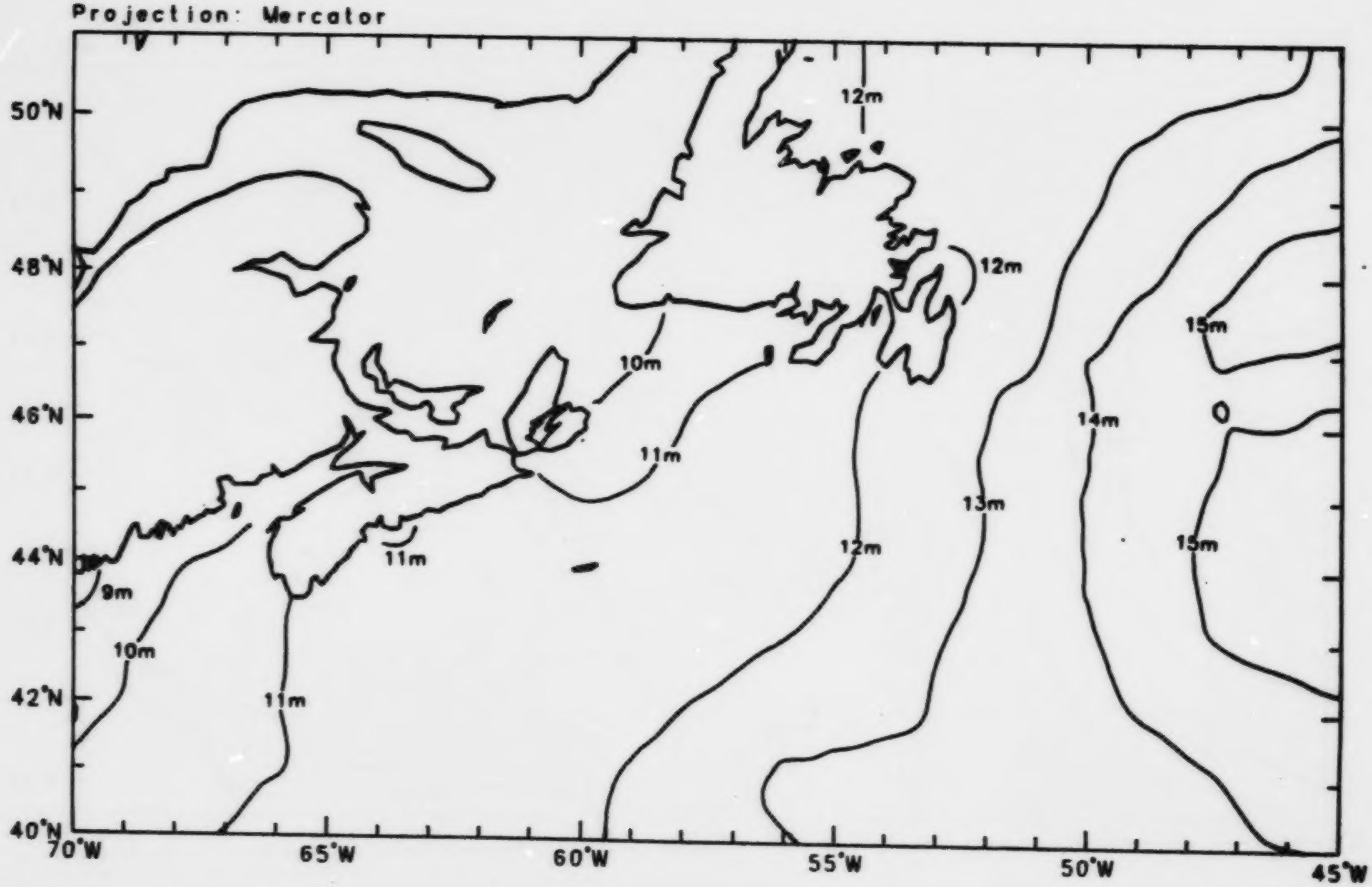

Significant Wave Height - 50 Year Return
Projection: Mercator
50°N
48°N
46°N
44°N
42°N
40°N
70°W
65°W
60°W
55°W
50°W
45°W
9m
9m
9m
10m
10m
11m
11m
11m
12m
12m
12m
13m
14m

Figure 7.6



Significant Wave Height - 100 Year Return

Figure 7.7

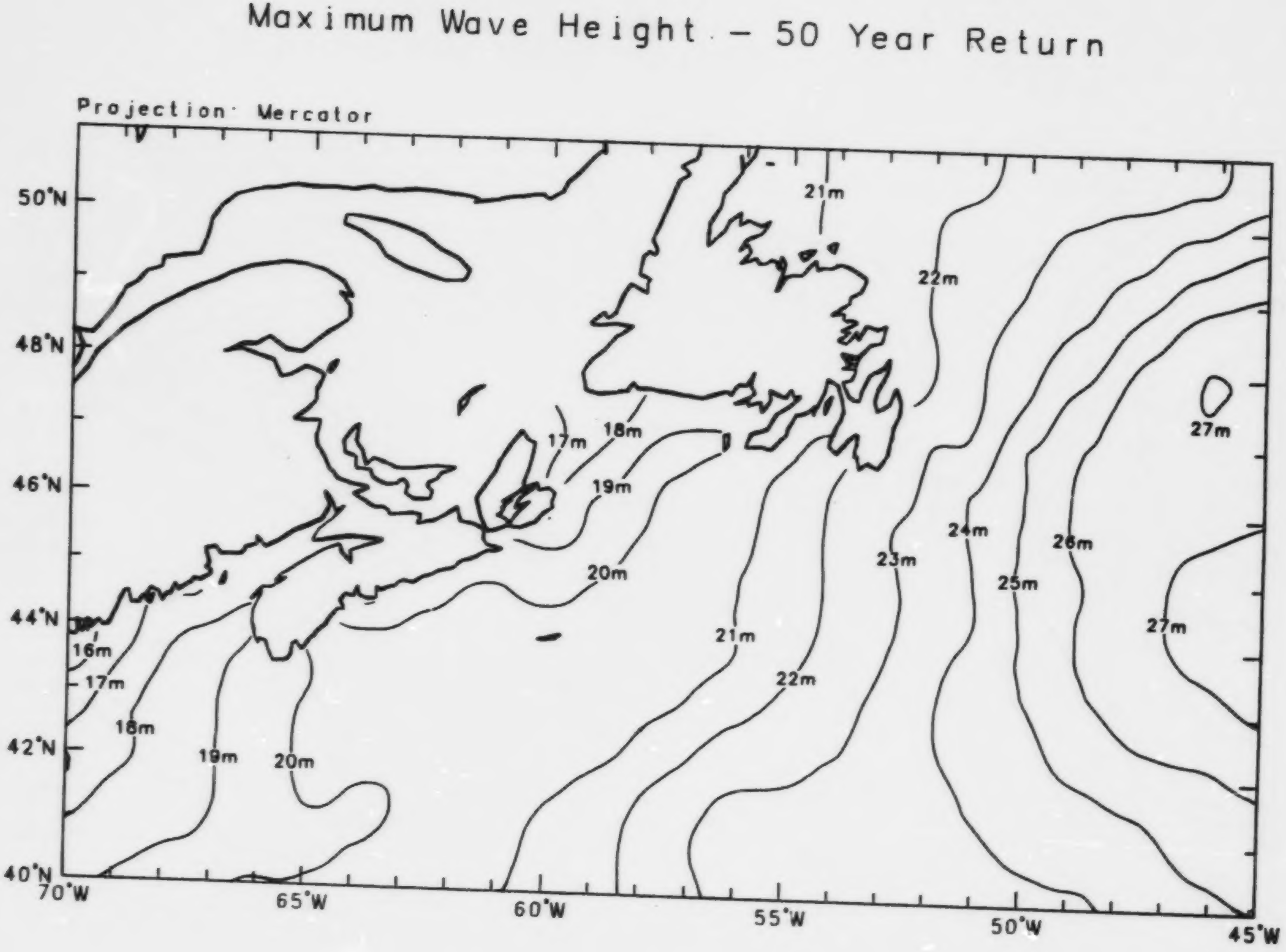
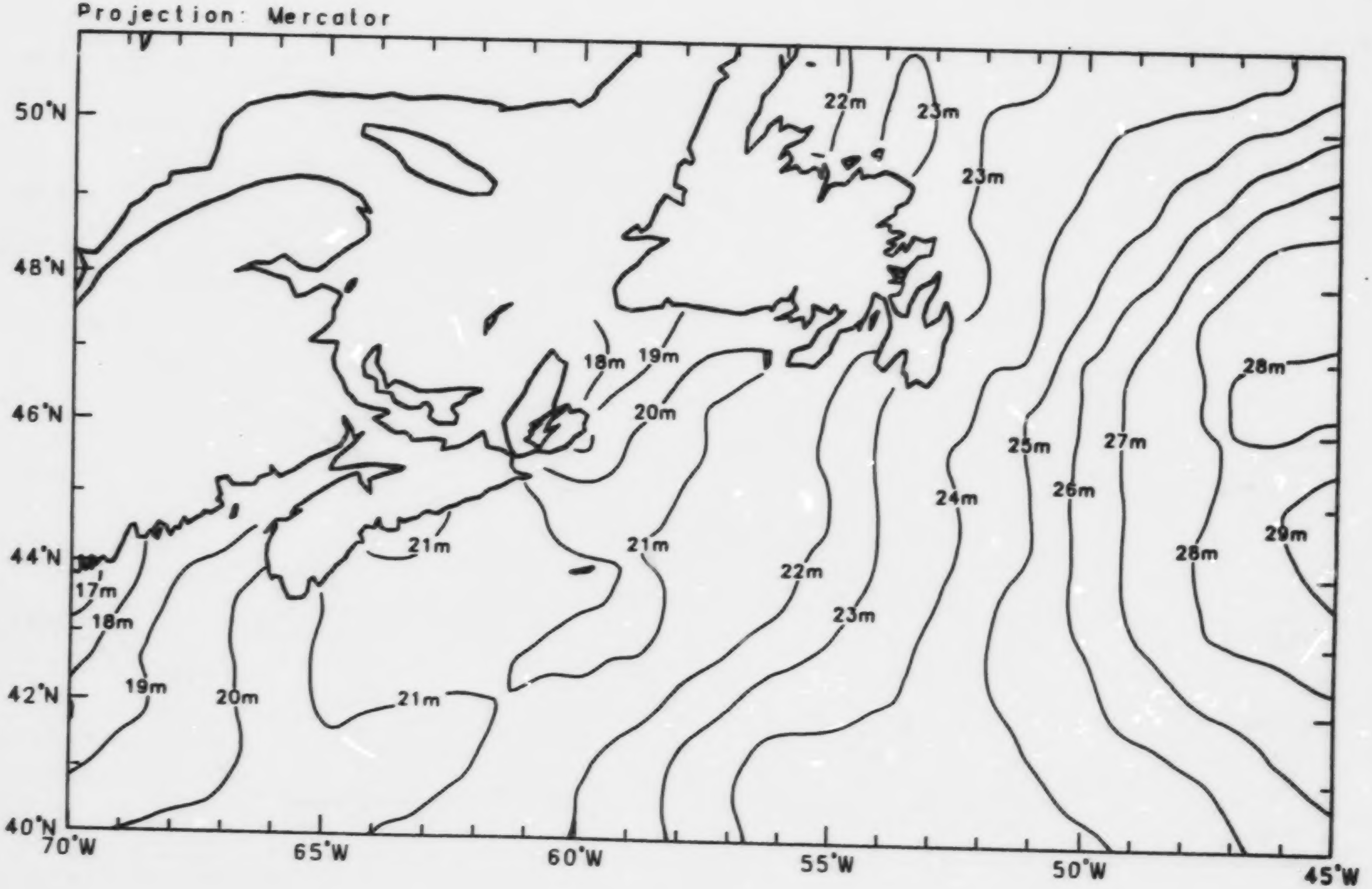

Maximum Wave Height - 50 Year Return
Projection: Mercator
50°N
48°N
46°N
44°N
42°N
40°N
70°W
65°W
60°W
55°W
50°W
45°W
16m
17m
18m
19m
20m
21m
22m
23m
24m
25m
26m
27m
17m
18m
19m
20m
21m
22m
27m

Figure 7.8



Maximum Wave Height – 100 Year Return

Figure 7.9

Wind Speed – 50 Year Return

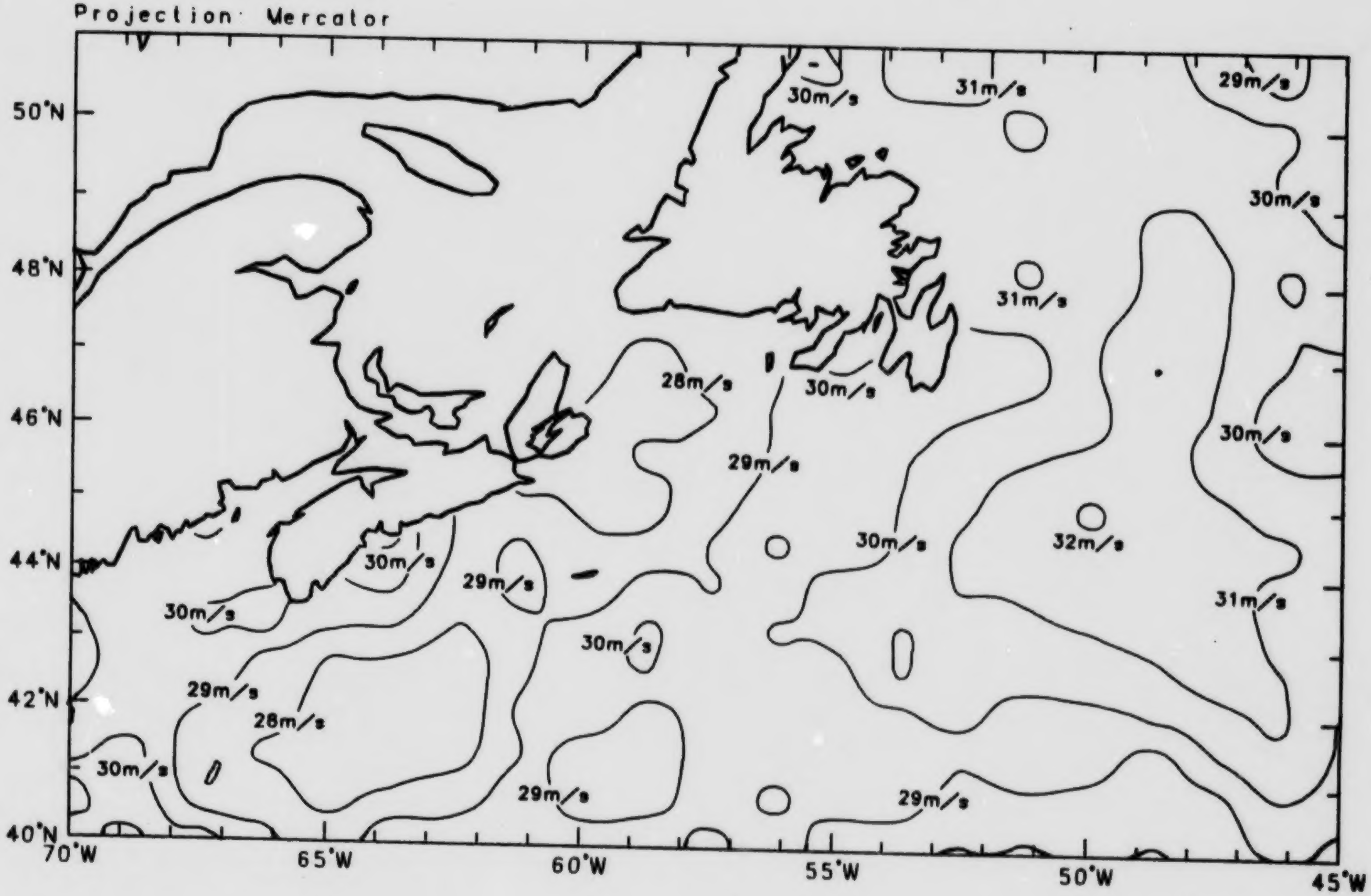


Figure 7.10

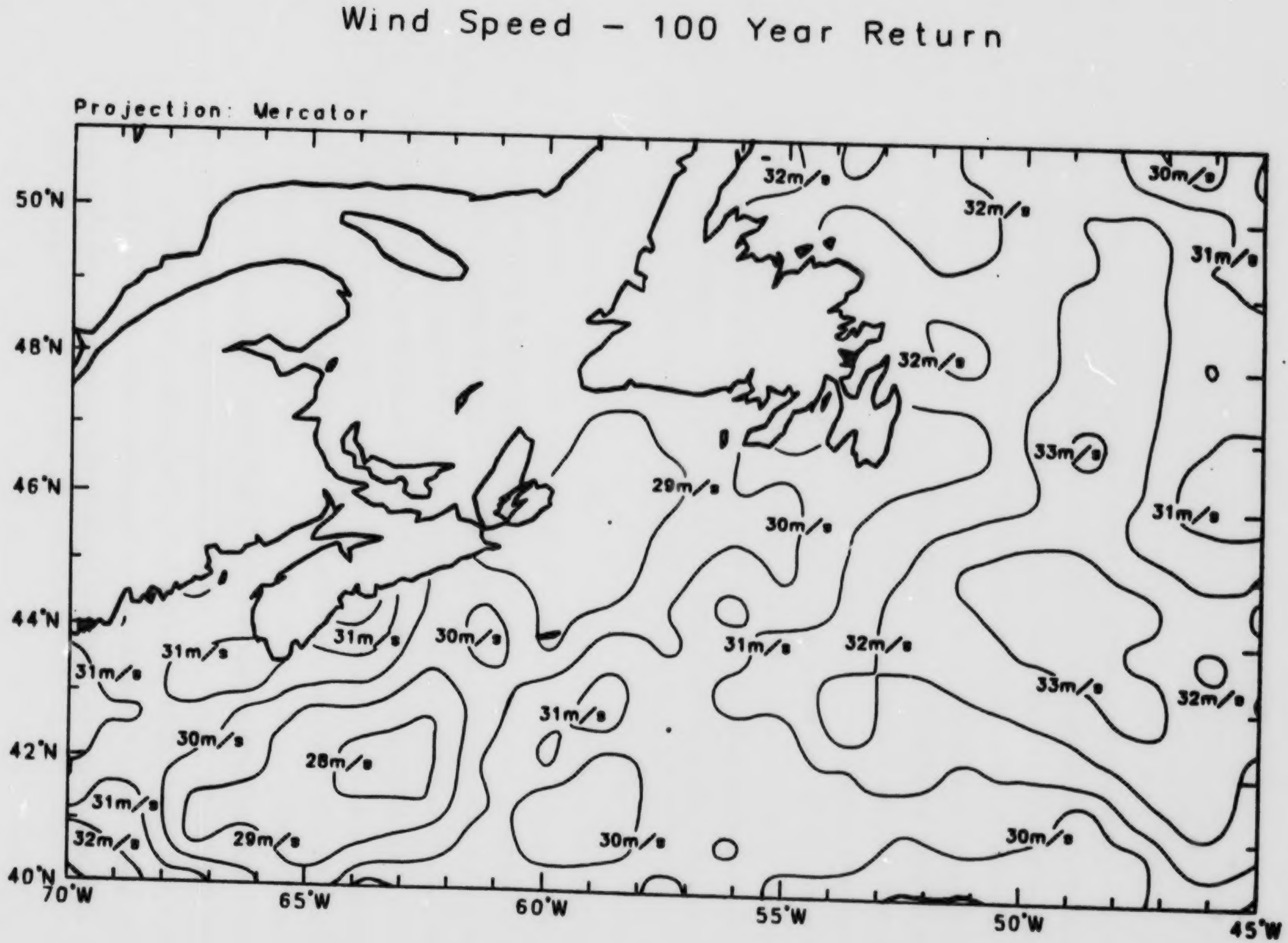

Wind Speed - 100 Year Return
Projection: Mercator
50°N
48°N
46°N
44°N
42°N
40°N
70°W
65°W
60°W
55°W
50°W
45°W
32m/s
30m/s
32m/s
31m/s
32m/s
33m/s
29m/s
30m/s
31m/s
31m/s
31m/s
30m/s
31m/s
32m/s
33m/s
32m/s
31m/s
31m/s
30m/s
28m/s
31m/s
32m/s
29m/s
30m/s
30m/s

Figure 7.11

8.0 SUMMARY, RESULTS AND RECOMMENDATIONS

8.1 SUMMARY

A hindcast approach was applied to specify the extreme wave climate in the Canadian East Coast offshore including deep water exploration areas on the Grand Banks of Newfoundland, the Scotian Shelf and Georges Bank. We adhered to the basic recipe of the hindcast approach, which includes the following steps: (1) assembly of a comprehensive data base of archived historical meteorological data, measured wave data and results of previous studies; (2) identification and ranking of historical storm occurrences over as long a period of history as possible, and selection of hindcast storms; (3) adoption and validation of the most accurate numerical procedures to specify time histories of surface wind fields, surface wave fields and directional wave spectra in each selected historical storm; (4) hindcast of 68 selected historical storms; (5) analysis of extremes at each hindcast model grid point to estimate the significant and maximum individual wave height, crest height, and associated wind speed and wave period, associated with rare return intervals.

The data base assembly was intended to be exhaustive, and tapped the resources of the Atmospheric Environment Service, the NOAA National Climatic Data Center, the MEDS, private industry, and products of numerous previous programs and studies conducted by government centres, and private industry, including the series of hindcast studies of the Venture (Scotian Shelf) and Hibernia (Grand Banks) fields, supported by Mobil Oil Canada Ltd. The historical meteorological and wave data assembled and referred to includes complete microfilm records of surface weather map series of AES-AWC and CMC and NOAA-NMC, digital files of previous long-term wave hindcast studies carried out by the U.S. Navy, U.S. Army and OWI, and of METOC wave analysis, digital files of synoptic observations from land stations, offshore rigs, lightships, buoys and ships, and wave measurements from MEDS buoys. The processing facilities of the AES CCAH (including MAST, LAST, DUST) were extensively utilized. Where data could not be obtained or accessed in computer compatible form, hard copies were obtained (e.g. "daily observation logs" from rigs, weather maps of MPL and OWI).

The storm selection work was designed to identify storms based on their potential to generate high sea states somewhere within the study area. This task proceeded in several stages. First, all the data sources noted above were studied and utilized to develop an initial candidate list of extratropical storms. A total of 532 events, which occurred within the period 1957-1988 comprised this initial list. This list was eventually refined and distilled to the final hindcast population of 68 events. The initial list was distilled in several stages, with the aid of both objective storm intensity ranking procedures, and subjective ranking and intensity assessments made by experienced meteorologists and wave modellers. Since the typical scale of an intense extratropical storm is large with respect to the study area, many selected storms affect more than one of the study sub-areas, and individual storms often overlap two or more areas. Thus the 68 storms include 33 "Grand Banks" events, 31 "Scotian Shelf" events and 25 "Georges Bank" events. At any given site therefore, the study is expected to include the 20-30 top-ranked extreme wave events associated with extratropical storms during the historical period considered.

Extreme sea states associated with tropical storms were considered only in the Georges Bank. For that area, a comprehensive storm selection was carried out, and pilot hindcasts of ten storms were made, in order to gain an understanding of the relative importance of tropical and extratropical storm generated extreme sea states in Georges Bank area. No extremal analysis of tropical cyclone hindcast results was carried out due to the small number of hindcast events.

The wind and wave hindcast methodology adapted to the basin of interest in this study has already undergone considerable refinement and validation in previous studies of this type. The specification of 6-hourly wind fields in each storm included a complete reanalysis of the evolution of the surface pressure field, starting with the best archived analysis available, and adding additional ship report, buoy and rig data not available in real time. Wind fields were then calculated from the pressure fields using a proven calibrated marine planetary boundary layer model. The assembled wind data were used to develop kinematic analyses as needed to provide winds of the highest accuracy achievable for the available data. The wave hindcasts were carried out with the ODGP spectral wave model adapted to the North Atlantic basin on a high-resolution nested grid, which provides temporal and spatial resolution of the wind and wave field in the study area of 2 hours, and average of about 85 km, respectively.

While the hindcast methodology adapted had already undergone extensive validation against measured data in east coast storms (e.g. the Hibernia, CASP and LIMEX/LEWEX studies), a substantial validation was included in this study, involving comparison of hindcasts of ten extreme storms against measured data at several sites. The ten storms selected overlap storms considered in the Hibernia study only slightly (3 storms). Our comparison of hindcast deep water model storm peak sea states generated in this study against raw measured storm peaks provided a mean difference of +.53 m and a scatter index of 13.2%. These may be compared to bias of +.26 m and scatter index of 12.8% in the previous validation of Hibernia hindcasts. In order to investigate the source of the increased positive bias found in the present hindcasts, the hindcasts were adjusted in an approximate way (TMA) for shallow water attenuation at shallow water sites before comparison. This procedure was found to change the sign of the mean error (to -0.59 m) and to decrease the scatter index slightly (from 13.2% to 11.2%), suggesting that in severe storms, and at sites in water depth less than about 80 m, shallow water processes are having an affect on the extreme wave climate. Overall, the peak-peak comparisons of H_s and T_p in the present hindcasts indicate skill comparable to the highest reported in previous studies of this kind. The overall scatter index of 13.2% in H_s noted above (11.2% if hindcast data are "adjusted" for shallow water) is at the lower end of the range of such indices reported for detailed hindcast studies of Northern Hemisphere extratropical storm regimes, using the most sophisticated modelling strategies.

The basic approach of the extremal analysis was to carry out site-specific hindcasts of peaks-over-threshold, at each grid point of the fine mesh hindcast model grid system. At each of the 118 points, the threshold was determined by allowing only the top-ranked 30 storms of the 68 storms hindcast. The first step of the analysis was to calculate the extreme maximum individual wave height (H_m) and crest height (H_c) in each storm at each point using the entire hindcast storm history. The peak H_s, H_m and H_c were then extrapolated to rare return period (up to 100 years) using the Gumbel distribution. The analysis included sensitivity studies on threshold, distribution function, and fitting scheme. The maximum wind speed associated with the extreme sea state was also extrapolated. The peak period associated with the maximum sea state was estimated from the hindcast data base using correlation analysis of the pairs T_p, H_s. The main extremal analysis considered hindcast peaks regardless of direction of approach. An attempt to develop extremes stratified by directional sector of wave approach met with limited success as it was found that the hindcast population was too small to resolve more than one or two very broad directional sectors.

8.2 RESULTS

The principal outcome of the study is the direct result of the site-specific extremal analysis at 118 points. The basic analysis provides estimates of extreme H_s and associated W_s for return periods of 2 - 100 years. For example, on Georges Bank, the extreme H_s varies between 10.1 m and 11.3 m, with corresponding wind speed from 28.7 m/s to 31.8 m/s. On Scotian Shelf, the 100-year H_s varies between 9.3 m and 11.7 m and the corresponding W_s varies between 27.9 and 32.7 m/s. On the Grand Banks, the 100-year H_s varies between 10.7 and 15.2 m and the corresponding W_s varies between 28.6 and 33.6 m/s. The wave height extremes apply to deep water, as the study suggests that at sites whose water depth is less than about 100 m, extremes are affected by water depth limitations, and except where local bathymetric features might cause refraction induced focusing of wave energy, extremes in shallow water may be lower than derived herein. More detailed extremal analysis was carried out at 25 grid points, at which, in addition to H_s and W_s, extremes of H_m, H_c, the ratios H_m/H_s, H_c/H_s and relations between T_p and H_s were given.

The study has also produced a number of secondary results. The most important of these is that the study has laid the foundation of a data base and analysis system which may be used to update these extremes as more resources become available, both by hindcasting additional storms which were found to be high-ranked, and as time passes, to add extreme storms which have occurred after 1988. The latter may be especially important if indeed the general circulation of the atmosphere is undergoing secular change in response to large scale external forcing (e.g. global warming). In addition, the population of storms hindcast can be expected to overlap adjacent areas, such as the Gulf of St. Lawrence and Labrador Sea, and the study provides a base of wind fields which can be augmented to derive the extreme wave climate in those areas, possibly using even more refined wave models (in fact, such studies are already underway, sponsored by Transportation Development Centre of Transport Canada for producing a Wind and Wave Climate Atlas for the East Coast of Canada).

Another important finding is the suggestion of the validation work that shallow water effects may be important in parts of the study area which may be considered deep water for operational purposes, but which exhibit a shallow water effect in severe storms. This study used a deep water hindcasting model and the results are to be considered as applicable to deep water (depths greater than about 80 m). The TMA scaling applied to selected hindcast data is merely intended to provide an indication of the degree of shallow water influence and not as a definitive shallow water model.

8.3 RECOMMENDATION FOR FURTHER STUDIES

This study and its results suggest a number of further studies. As mentioned above, the study may be logically enhanced most directly by the addition of more storms. The study area is very active, and the storm selection identified a large number of storms. The later stages of refinement of storm lists required increasingly subjective assessments, raising the possibility that some storms which exceed the threshold of intensity ultimately established at each point may have been missed. However, it is extremely unlikely that any storms which would have ranked within, say, the upper half of the storms actually fitted were missed. Still, greater confidence in the extrapolations would follow from larger and reliably ranked storm populations. One possibility would be to use the production hindcast results themselves to refine the storm selection process, and to apply the refined selection criteria to the initial storm list to check that high ranked storms have not been incorrectly rejected.

This study strongly suggests that further study of shallow water effects should be carried out. These would include not only incorporation of shallow water source terms and inclusion of refraction and shoaling in the wave model but also investigation of the effects of shallow water on the estimation of maximum individual wave height and crest height.

Finally, the validation of the hindcast methodology involved hindcasts of only 10 storms (so-called validation storm hindcasts). No doubt, there exists considerable measured wave data in many of the other storms hindcast in the production phase of the study. While those data may not be of a high-quality as the data used for validation, it would be useful to compare as much hindcast and measured data as possible, and to calculate standard measures of difference.

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APPENDIX A

- Storms List from Literature
- Master Candidate List (MCL) for Extratropical Storms

SCOTIAN SHELF

COMPILED FROM PREVIOUS STUDIES

CCC = Canadian Climate Centre Report #84-13

MEP = ESRF Study Report #020, 1986 by MEP; Brown et al. (1986)

VDP = Venture Development Project, Top Ranked Storm List; MPL (1985)

DATE	SOURCE(S)
Apr 5, 1949	MEP
Mar 3, 1951	MEP
Feb 18, 1952	MEP
Dec 1, 1952	MEP
Dec 3, 1953	MEP
Jan 3-4, 1955	MEP, VDP
Jan 14, 1955	MEP, VDP
Sep 21, 1955	MEP
Jan 6, 1956	VDP
Jan 9, 1956	MEP, VDP
Jan 11-12, 1957	CCC
Apr 9-11, 1957	CCC
Mar 28-29, 1958	MEP, VDP
Apr 1-2, 1958	MEP, VDP
Sep 29-30, 1958	CCC
Dec 31/58 - Jan 1/59	CCC
Apr 15-17, 1959	CCC
Dec 22-24, 1959	CCC, VDP
Jan 16-17, 1960	CCC
Dec 12-14, 1960	CCC
Dec 17-18, 1960	CCC
Jan 21-22, 1961	CCC
Feb 5, 1961	VDP

SCOTIAN SHELF
(Cont'd)

DATE	SOURCE(S)
Oct 29-30, 1963	CCC
Dec 15-18, 1963	CCC
Dec 19-21, 1963	CCC, VDP
Feb 9-11, 1964	CCC
Feb 16-19, 1964	CCC
Feb 29 - Mar 2, 1964	CCC
Mar 24, 1964	MEP, VDP
Mar 31 - Apr 2, 1964	CCC
Dec 1, 1964	VDP
Feb 1, 1965	VDP
Feb 22-24, 1965	CCC
Mar 27-30, 1965	CCC
Jan 9-11, 1966	CCC
Jan 27-30, 1966	CCC, MEP
Feb 14-20, 1966	CCC
Jan 2-5, 1967	CCC, VDP
Feb. 16-18, 1967	CCC
Feb 21-23, 1967	CCC, MEP, VDP
Apr 29, 1967	MEP
Jan 6, 1968	MEP
Apr 30 - May 1, 1968	CCC
Nov 26-29, 1968	CCC
Feb 10, 1969	VDP
Feb 19, 1969	MEP
Mar 8-9, 1969	CCC
Jan 21-23, 1970	CCC, VDP
Apr 3-5, 1970	CCC
Dec 26-29, 1970	CCC
Nov 14-19, 1971	CCC, MEP
Jan 4, 1972	MEP
Jan 26-27, 1972	CCC
Feb 19-21, 1972	CCC

SCOTIAN SHELF
(Cont'd)

DATE	SOURCE(S)
Feb 27-28, 1972	CCC
Feb 12, 1973	MEP
Mar 22-24, 1973	CCC, MEP, VDP
Jun 17-18, 1973	CCC
Oct 28-29, 1973	CCC
Nov 2, 1973	MEP
Feb 1-3, 1974	CCC
Feb 5-7, 1974	CCC, MEP, VDP
Feb 17-20, 1974	CCC
Feb 20-22, 1974	CCC
Mar 11-13, 1974	CCC, MEP
Mar 27, 30, 1974	CCC, MEP
Oct 20-21, 1974	CCC, VDP
Apr 3, 1975	VDP
July 28, 1975	CCC
Dec 23, 1975	MEP
Feb 2-4, 1976	CCC
Mar 17-19, 1976	CCC, VDP
Jun 13-14, 1976	CCC
Nov 8, 1976	VDP
Nov 19-21, 1976	CCC, VDP
Jan 10-12, 1977	CCC
Jan 29-30, 1977	CCC
Dec 16-20, 1977	CCC
Jan 3-5, 1978	CCC
Feb 7, 1978	VDP
Mar 4-8, 1978	CCC
Dec 18-22, 1978	CCC
Feb 6-8, 1979	CCC
Mar 26-27, 1979	CCC
Jan 24-26, 1980	CCC

SCOTIAN SHELF
(Cont'd)

DATE	SOURCE(S)
Jan 8-9, 1981	CCC
Jan 11-12, 1981	CCC
Mar 8, 1981	MEP
Dec 16, 1981	VDP
Jan 15-17, 1982	CCC, VDP, MEP
Feb 14-15, 1982	CCC, MEP
Feb 24-28, 1982	CCC
Jan 7, 1983	CCC
Dec 25-26, 1983	CCC

GRAND BANKS
COMPILED FROM PREVIOUS STUDIES

DATE	SOURCE(S)
Dec 14, 1951	MEP
Nov 13, 1952	HWHS
Feb 2, 1954	HWHS
Sep 22, 1955	HWHS
Dec 11, 1955	HWHS
Mar 16, 1956	MEP
Jan 11-12, 1957	CCC
Jan 24, 1957	MEP
Feb 9, 1957	CCC
Apr 9-11, 1957	CCC
Dec 6, 1957	MEP
Sep 29-30, 1958	CCC
Dec 31/58 - Jan 4/59	CCC
Feb 8, 1959	MEP
Feb 16, 1959	CCC
Mar 13-15, 1959	CCC
Apr 15-17, 1959	MEP, CCC
Dec 20-21, 1959	CCC
Dec 12-14, 1960	CCC
Jan 21-22, 1961	MEP, CCC, HWHS
Mar 8-9, 1961	CCC
Dec 6, 1961	MEP
Dec 15-18, 1961	CCC, HWHS, MEP
Jan 5-6, 1962	CCC
Jan 28-29, 1962	CCC
Feb 25-27, 1962	CCC, MEP
Dec 30/62 - Jan 2/63	CCC
Feb 28 - Mar 1, 1963	CCC
Mar 11-13, 1963	CCC
Aug 27-28, 1963	CCC
Oct 11-13, 1963	CCC
Dec 15-18, 1963	CCC

HWHS = Hibernia Wave Hindcast Study, MPL (1985)

GRAND BANKS
(Cont'd)

DATE	SOURCE(S)
Dec 19-21, 1963	CCC
Jan 11, 1964	MEP
Jan 13, 1964	HWHS
Feb 9-11, 1964	CCC
Feb 15-16, 1964	CCC
Feb 16-19, 1964	CCC
Feb 29 - Mar 2, 1964	CCC, MEP
Mar 14-15, 1964	CCC, MEP
Mar 18, 1964	HWHS
Mar 31 - Apr 2, 1964	CCC
Sep 4-5, 1964	CCC
Jan 26, 1965	MEP
Feb 16-20, 1965	CCC, MEP, HWHS
Feb 22-24, 1965	CCC
Mar 27-30, 1965	CCC
Dec 18-20, 1965	CCC
Jan 9-11, 1966	CCC, MEP
Jan 27-30, 1966	CCC
Feb 14-20, 1966	CCC, MEP, HWHS
Feb 24, 1966	HWHS
Apr 6-7, 1966	CCC
Jan 2-5, 1967	CCC
Feb 16-18, 1967	CCC, MEP
Feb 21-23, 1967	CCC, MEP, HWHS
Dec 1-3, 1967	CCC
Jan 5, 1968	MEP
Apr 30 - May 1, 1968	CCC
Nov 26-29, 1968	CCC
Mar 8-9, 1969	CCC
Jan 21-23, 1970	CCC, MEP, HWHS
Dec 26-29, 1970	CCC

GRAND BANKS
(Cont'd)

DATE	SOURCE(S)
Jan 17, 1971	MEP, HWHS
Nov 14-19, 1971	CCC
Jan 5, 1972	MEP
Feb 20, 1972	MEP, CCC
Feb 22-24, 1972	CCC
Feb 27-28, 1972	CCC
Apr 18-21, 1972	CCC
May 10-12, 1972	CCC
Dec 13-16, 1972	CCC, MEP
Dec 29, 1972	MEP
Jan 12-15, 1973	CCC
Feb 22-24, 1973	CCC
Jun 17-18, 1973	CCC
Oct 28-29, 1973	CCC, HWHS
Nov 23-25, 1973	CCC
Jan 2-6, 1974	CCC
Jan 20, 1974	MEP
Feb 1-3, 1974	CCC
Feb 5-7, 1974	CCC
Feb 17-20, 1974	CCC
Feb 20-22, 1974	CCC
Mar 11-13, 1974	CCC, MEP, HWHS
Mar 27-30, 1974	CCC, MEP
Mar 17-19, 1976	CCC
Jun 13-14, 1976	CCC
Mar 18, 1976	HWHS
Nov 19-21, 1976	CCC
Jan 21, 1977	HWHS
Jan 29-30, 1977	CCC
Mar 8-9, 1977	CCC
Jul 23-24, 1977	CCC

GRAND BANKS
(Cont'd)

DATE	SOURCE(S)
Dec 10-12, 1977	CCC
Dec 16-20, 1977	CCC
Jan 3-5, 1978	CCC
Feb 12-18, 1978	CCC
Mar 3-4, 1978	CCC, MEP, HWHS
Mar 4-8, 1978	CCC
Apr 1-2, 1978	CCC
Dec 18-22, 1978	CCC
Feb 6-8, 1979	CCC
Oct 23-24, 1979	CCC
Nov 17-19, 1979	CCC
Jan 4, 1980	HWHS
Jan 24-26, 1980	CCC
Feb 11-13, 1980	CCC
May 23, 1980	CCC
Jan 3-4, 1981	CCC
Mar 8, 1981	MEP
Jan 15-17, 1982	CCC, MEP, HWHS
Feb 2, 1982	HWHS
Feb 14-15, 1982	CCC, MEP, HWHS
Feb 24-28, 1982	CCC
Apr 10-11, 982	CCC
Dec 10, 1982	CCC, HWHS
Jan 7, 1983	CCC
Feb 12-14, 1983	CCC
Feb 16-18, 1983	CCC
Mar 8-9, 1983	CCC, HWHS
Aug 31, 1983	CCC
Dec 1, 1983	HWHS
Dec 20-23, 1983	CCC, HWHS
Dec 22, 1983	HWHS
Dec 25 - 26, 1983	CCC, HWHS
TOTAL, 126	

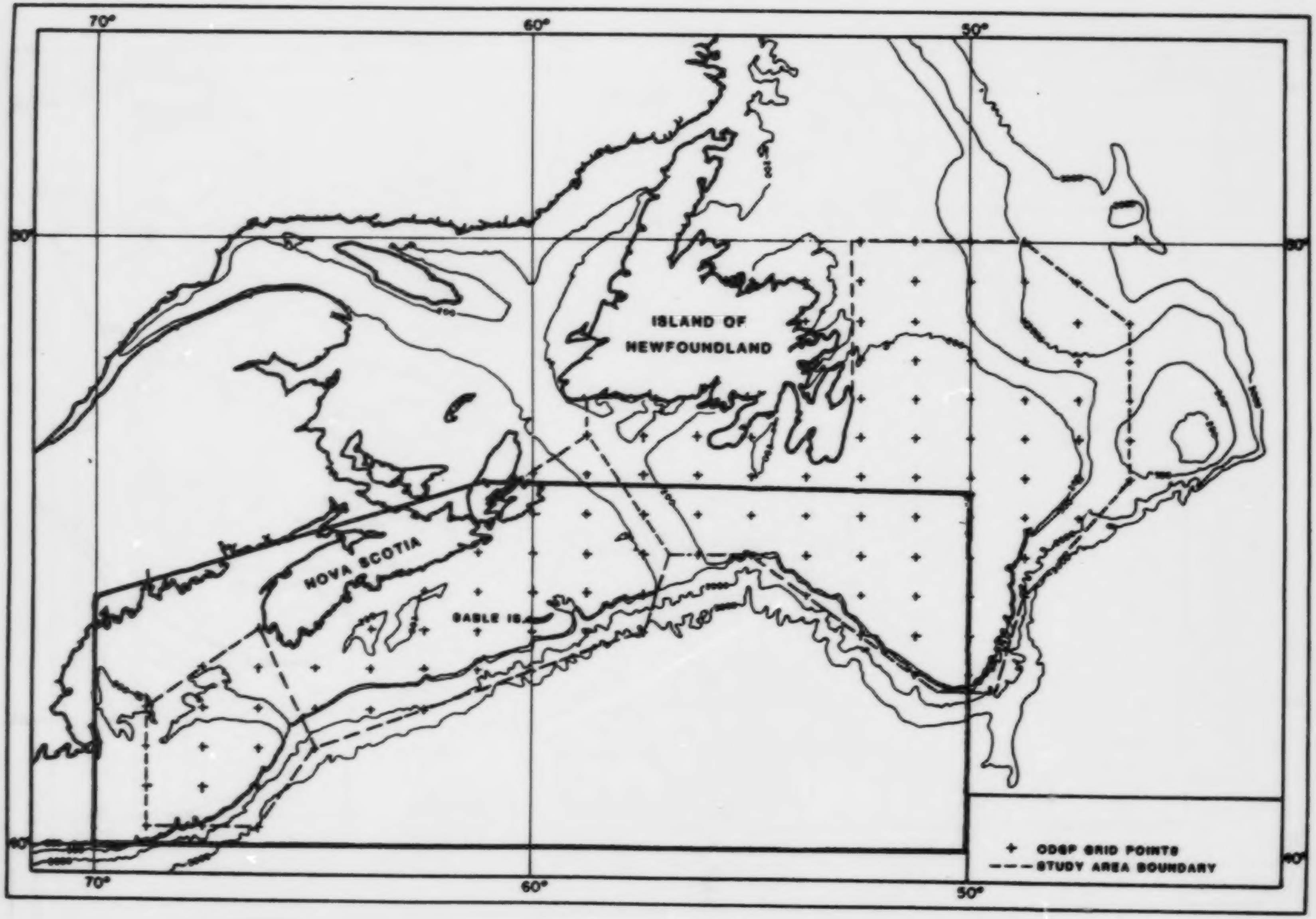


Figure A-1: Scotian Shelf/Georges Bank MAST Run Area

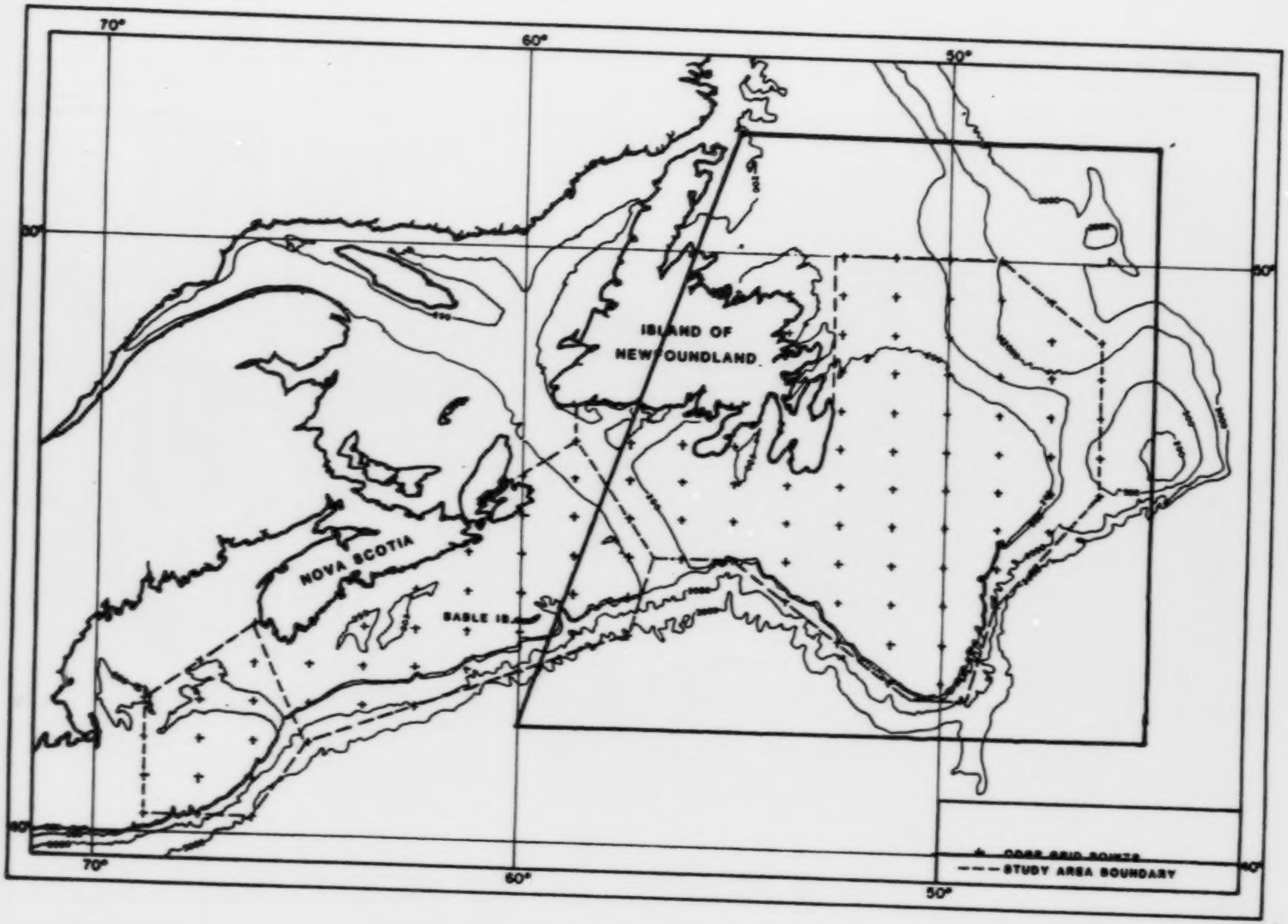


Figure A-2: Grand Banks MAST Run Area

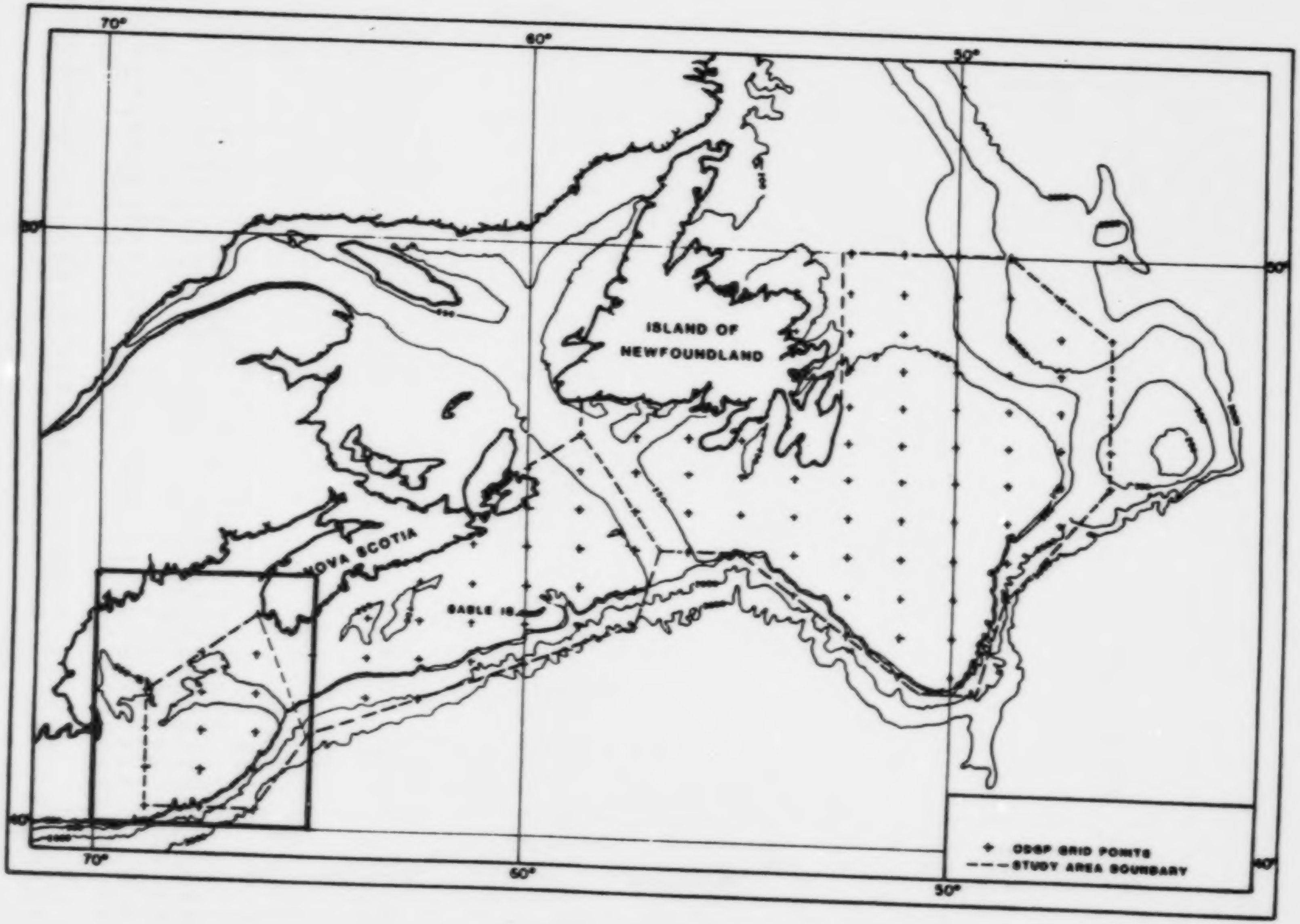


Figure A-3: Georges Bank MAST Run Area

TABLE A-2

Master Candidate List (MCL) of Scotian Shelf (SS), Grand Banks (SB) and Georges Bank (EB) Storms

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	NEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
1	GB	570106	P	A1	6.1	6.1									2
2	SS,GB	570108,570109	P,O	D,I,A1	8.2	6.7									4,2
3	SS,GB	570111,570112	P,O	B,C,I,L,A1	8.5	8.2						6.4			5,5
4	SS	570117	P,O	C,I											3
5	SS,GB	570124,570125	P	D,A1,M	10.4	8.8				12.8					5,5
6	GB	570206	P	A1	9.1	10.1									2
7	GB	570211	P	A1	9.1	8.8									4
8	GB	570214	P	A1	4.9	-									1
9	SS	570218	P	C											4
10	SS	570313	P	B,C											3
11	GB	570329	O	I,M	9.8	11.9					11.9				4
12	SS	570404	P	B								6.7			3
13	SS	570410	P,O	B,C,I,L								6.6			5
14	GB	570426	P	C,A1	6.7	4.9									3
15	GB	570523	P	A1	7.6	6.4									2
16	GB	571114	P	A1	7.9	7.9									3
17	GB	571128	P	A1	7.6	7.9									2
18	SS,GB	571201,571202	P,O	B,C,I	5.2	5.2									5,2
19	SS,GB	571205,571206	P,O	B,C,I,M	7.3	7.9				12.5		6.1			4,1
20	SS	580108	O	I								6.7			5
21	SS	580115	P	D											2
22	SS	580120	O	I											4
23	SS,GB	580128,580130	P	D,A1	8.2	8.5									4,3
24	SS	580202	O	I											3
25	SS	580214	O	I											5
26	GB	580326	O	W	7.3	9.5									1
27	SS	580328	P,O	B,C,I											2
28	SS	580402	P,O	B,C,D,S								6.7			5
29	SS	580929	P,O	B,L											HUR
30	GB	581017	P	A1	4.9	4.6									5
31	SS,GB	581111,581112	P	B,A1	4.9	3.7									2,0
32	GB	581126	P	A1	6.7	9.1									3
33	SS,GB	581129,581201	P	D,A1	5.2	4.9									4,1
34	SS,GB	581203,581204	O,P	I,A1	6.1	4.6									3,3
35	SS	581207	P	D											4
36	SS,GB	590102,590102	P,O	D,L,W	9.1	7.3						6.4			5,4
37	SS	590105	P	B,C								7.3			5
38	GB	590116	O	W	9.1	9.5									4
39	SS	590117	O	M								6.9			3
40	SS,GB	590207,590208	P,O	C,A1,I,M	14.0	10.1				16.1		6.1			3,5
41	SS,GB	590216,590217	P,O	B,C,I,L,A1	9.1	6.7									4,4
42	SS,GB	590219,590220	P	D,A1	7.0	6.7									4,3
43	SS	590307	O	M								6.7			2

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
44	SS	590313	P,O	B,C,D,I.L								11.9			5
45	SS	590323	P	D											4
46	SS	590329	O	I											4
47	SS,GB	590415,590416	P,O	B,C,L,M	8.5	7.3				12.3			10.5		5,4
48	GB	590511	P	A1	6.7	4.6									1
49	SS	590620	O	I											0
50	GB	591121	P	A1	NA	7.0									1
51	SS	591126	O	I											5
52	SS,GB	591220,591221	P,O	B,C,I,L,A1	NA	8.5									1,5
53	SS,GB	591223,591224	P,O	B,C,I,L,A1	NA	8.2									5,5
54	SS,GB	600109,600110	P	B,A1	NA	7.6									0,5
55	SS	600117	P	C,D,L											3
56	SS	600120	P	A								6.2			3
57	SS	600204	P	B,C,D								6.4			1
58	SS	600219	O	M								7.7			4
59	SS,GB	600304,600305	P,O	B,C,D,I,A1	9.8	9.5						7.4			5,3
60	SS,GB	600310,600310	P,O	B,C,I,A1	5.5	4.0									5,1
61	SS,GB	600311,600312	P,O	B,C,I,A1	4.9	4.3									4,1
62	SS,GB	600314,600316	P,O	B,C,I,A1	6.7	6.4									4,3
63	GB	600321	O	W,M	10.7	8.5				14.0					5
64	GB	601119	P	A1	6.7	6.7									4
65	GB	601127	P	A1	7.9	9.1									3
66	SS	601205	P	B,C											3
67	SS	601213	P,O	B,C,I,L								6.5			5
68	SS	601217	P	A,B,L											5
69	SS	610105	O	I											5
70	SS,GB	610121,610122	P,O	B,C,I,L,M,A1,S	15.5	11.0		11.7		15.7	11.0	7.8	10.5	10.4	5,4
71	GB	610127	O	W	9.1	8.2									2
72	GB	610201	P	A1	4.3	6.1									4
73	GB	610217	P	A1	7.0	7.9									1
74	SS	610226	O	M								8.3			3
75	SS,GB	610303,610304	P	B,C,A1	9.1	6.7									3,3
76	GB	610310	P	A1,L	9.1	6.1									2
77	SS	610310	P	A,D											5
78	SS	610315	P	B,C											4
79	SS,GB	610321,610321	P,O	B,C,I,A1	7.0	4.9									5,2
80	GB	611012	P	A1	6.7	7.6									2
81	SS	611021	P	B,C,A1											HUR
82	SS	611024	P	B											1
83	GB	611206	P	A1	7.6	6.4									3
84	SS,GB	611209,611211	P	B,C,A1,M	7.9	8.8					12.6				2,0
85	SS,GB	611215,611217	P,O	B,C,L,A1,S,M	14.0	13.1		9.7		14.9	13.2				3,5
86	SS,GB	611225,611228	P,O	B,W,M	7.3	11.0					11.0				5,4

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
87	SS,GB	620102,620103	P,O	C,A1,I	6.1	7.9									4,0
88	SS,GB	620105,620106	P,O	C,A1,I,L	9.8	9.8									2,5
89	GB	620110	O	W	9.1	9.5									1
90	GB	620128	P	A1,L	5.8	5.5									5
91	SS	620212	O	N								7.0			2
92	GB	620216	O	W	9.1	7.6									2
93	SS,GB	620218,620220	P	B,C,A1	7.0	8.2									5,2
94	SS,GB	620225,620226	P,O	A,C,I,L,A1,N	9.8	9.8					12.7				3,3
95	SS	620308	P,O	B,C,I,L,N								13.0	15.5	10.5	3
96	GB	620313	P	B,C	8.2	7.9									1
97	SS	620314	P	B,C											2
98	SS	620323	O	I								7.3			4
99	GB	620502	P	A1,W	10.4	9.1									3
100	SS,GB	621008,621010	O,P	I,A1	3.7	5.8									HUR,0
101	SS	621011	P,O	B,C,I											2
102	SS	621116	P,O	D,I								7.7			5
103	SS	621123	O	N								6.3			3
104	SS	621207	O	N								6.1			3
105	SS	621221	P	B,C											4
106	SS	621231	P	B,D,L											5
107	SS	630121	O	N								7.5			3
108	SS	630128	P	D								6.6			4
109	SS,GB	630213,630217	P	B,C,A1	7.6	8.2									1,1
110	SS	630220	P	B,C,M								7.3	10.6		4
111	SS,GB	630225,630226	P,O	B,C,W	9.5	7.9									4,4
112	GB	630228	O	W	6.4	10.4									5
113	SS	630307	O	N								6.7			4
114	SS,GB	630312,630313	P,O	B,C,I,L,N	8.2	6.4					12.5				5,2
115	SS,GB	630315,630318	P	B,A1	7.6	7.3									1,0
116	SS	630405	P	B,C											4
117	SS	630409	P,O	B,C,I											4
118	SS	630425	P,O	B,I											5
119	EB	631029	O	I											HUR
120	SS	631108	O	M									10.5		2
121	GB	631116	O	I	9.5	9.5									5
122	SS	631130	O	N,L								6.8			3
123	SS	631216	P	B,C,L											3
124	SS,GB	631220,631220	P,O	A,B,C,D,I,L,A1	11.0	8.8									5,4
125	GB	631227	O	W	9.8	9.1									4
126	GB	631231	O	I,L	10.1	10.1									5
127	GB	640109	O	I	8.5	9.5									4
128	SS,GB	640111,640111	O,P	M,A1,S	9.5	13.4		6.3			13.5			10.2	5,3
129	SS,GB	640114,640116	P	A1,M	12.2	10.4				13.7					4,5

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	NEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
130	SS	640121	O	N								6.8			2
131	SS	640203	P	A,D								7.2			4
132	SS,GB	640209,640210	P,O	B,C,I,L,A1	11.0	8.8						6.6			5,4
133	GB	640216	O	M,L,W	9.5	8.2					13.9				4
134	SS	640217	P,O	B,C,D,I,L								7.0			5
135	GB	640223	O	W	8.2	9.8									4
136	GB	640228	O	W	7.0	10.1									1
137	SS,GB	640301,640302	P,O	B,C,I,L,W,M	10.7	8.8					13.8	7.3			5,3
138	SS,GB	640311,640312	O,P	N,A1,	6.7	6.4						6.5			2,0
139	GB	640315	P,O	A1,L,W	10.4	9.5									4
140	SS,GB	640316,640318	P,O	A,S,M	12.8	14.3		8.4		15.1	14.2				1,5
141	SS,GB	640320,640322	P,O	A,B,C,I	7.3	5.2						6.6			5,2
142	SS,GB	640324,640325	P,O	B,C,S,M	8.8	6.7						10.8	12.7		5,2
143	SS	640327	O	N								6.7			0
144	SS	640331	P	A,B,L											5
145	SS	640404	P	B,C								6.3			3
146	GB	641104	O	I	9.8	9.8									4
147	SS	641202	P,O	A,B,C,D,I								7.6			5
148	SS,GB	641219,641219	P,O	B,C,I,A1,M	7.9	8.5					10.9				2,3
149	SS	650102	P,O	B,I								7.6			5
150	SS	650117	O	N								6.2			0
151	GB	650124	P	A1	9.8	10.1									5
152	SS,GB	650126,650127	P,O	B,I	9.5	6.1									4,2
153	SS,GB	650201,650202	P,O	B,C,I,W	9.5	9.8						6.5			4,3
154	GB	650219	P,O	A1,S,L,M	12.5	11.6		9.8		12.6	11.5				3
155	SS	650220	P,O	B,C,I											5
156	SS	650223	P	B,C,D,L											5
157	SS	650226	P	D								6.5			5
158	SS,GB	650312,650313	P,O	B,C,W	9.5	7.6									2,4
159	GB	650322	P	A1	8.5	7.6									5
160	SS,GB	650328,650328	P	B,C,L,A1	10.7	9.5									5,2
161	GB	651021	O	W	6.1	9.5									2
162	SS,GB	651029,651031	P	B,C,W	6.7	9.5									1,3
163	GB	651213	P	A1	8.5	10.1									3
164	GB	651219	P	A1,L	8.5	7.3									4
165	GB	651228	P	A1	9.8	9.1									2
166	GB	660103	P,O	A1,I,	9.8	11.6									3
167	SS,GB	660104,660105	P,O	B,C,A1,M	9.8	10.7					12.3				3,4
168	SS,GB	660107,660107	P,O	B,C,A1,	7.6	7.9									2,0
169	SS,GB	660109,660110	P,O	A,B,C,I,L,M	10.4	10.1					13.6			9.9	5,4
170	SS,GB	660117,660118	P	B,C,M,A1	7.6	7.0								11.3	3,5
171	SS,GB	660124,660126	P	B,C,A1,M	11.3	7.3				14.2					4,2
172	SS,GB	660129,660130	P,O	A,B,C,I,L,M,W	7.6	9.5					11.6	10.1	12.0	13.0	4,2

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
173	EB	660130	O	I											5
174	SS,GB	660214,660216	O,P	L,A1,S,M,A,B	13.7	16.8		10.4		15.9	16.6	7.7			2,4
175	SS,GB	660217,660218	P,O	A1,A,B,C,W	11.6	11.6									3,4
176	GB	660223	P,O	A1,S,M	11.6	14.0		8.9		14.1	14.1				5
177	EB	660226	O	I											3
178	SS	660302	O	M,N								7.4		9.8	3
179	SS	660306	O	N								6.3			0
180	GB	660409	O	W,L	8.5	9.5									2
181	SS	660414	P	A,B											2
182	GB	660420	O	W	10.1	7.0									2
183	GB	660428	O	W	9.5	9.1									4
184	SS	661225	P	B,C								6.4			4
185	SS,GB	670103,670104	O	M,L,W	10.1	6.1								10.2	5,2
186	SS,GB	670122,670126	O	I,W,M	7.3	11.9				12.3	12.0				0,1
187	SS,GB	670210,670214	P,O	A,B,C,I	9.1	10.4									2,1
188	SS,GB	670216,670217	P,O	A,B,L,W,M	11.3	10.1				13.0		8.9			3,4
189	SS,GB	670222,670222	P,O	B,C,S,L,M,A1	14.9	12.5		11.9		16.5	12.6	6.3	11.7	10.6	5,5
190	SS,GB	670224,670224	P,O	A,B,C,D,I,W	6.7	9.1									4,0
191	SS	670302	P	A											3
192	SS	670308	O	N								9.3			3
193	SS	670326	P	B,C											0
194	SS	670331	O	M,N								6.3	10.6		2
195	SS	670428	P	A,B,C,M								6.7	11.2		5
196	SS	670508	O	N								6.1			1
197	SS,GB	671202,671203	P	A,B,C,L,A1	6.4	4.9						6.5			4,2
198	SS	671205	P	C											2
199	EB	671229	O	I											1
200	SS,GB	680105,680106	P,O	B,C,I,M,A1	10.7	12.2					12.1			11.2	5,5
201	SS	680108	P,O	B,D,I,M								6.6		12.5	4
202	SS	680220	P	A											2
203	SS	680302	P,O	D,I,M								9.4	10.9	10.2	4
204	SS	680314	P	D								6.6			1
205	SS	680501	P,O	A,I,L											5
206	SS	680917	P	A,B,C											1
207	GB	681110	O	W	6.7	10.1									0
208	EB	681111	O	I											2
209	GB	681117	P	A1	6.1	6.4									2
210	SS	681126	P	C,L											5
211	SS	681206	P,O	B,C,D,I								6.9			4
212	SS	681229	O	N								6.2			1
213	SS	690102	P	D								6.3			5
214	GB	690121	P	A1,M	8.5	10.1					14.5				4
215	SS	690210	O	I,M								7.0	11.1		5

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB SOWM	ARMY	METOC	OWI	NEDS	SOWM (ESRF)	ARMY (ESRF)	PEAK HS(M)-SS NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	TAR #
216	SS	690219	O	I,M								10.3	10.5	12.2	4
217	SS,GB	690308,690308	P,O	A1,L,M,I	9.8	7.6					12.6		10.6		5,4
218	SS	690310	P	A,B,L											3
219	SS	690320	O	N								7.3			4
220	SS	690403	P	A											1
221	SS	691029	P	A,B											2
222	SS	691130	O	I											5
223	SS	691227	O	I								7.0			5
224	GB	700108	O	W	6.1	9.5	4.3								1
225	GB	700116	O	M	5.2	5.8	4.9				11.6				0
226	SS,GB	700122,700123	P,O	A,B,C,S,L,A1	11.0	12.5	9.8	12.2			12.6			13.1	5,4
227	SS	700130	O	N								7.0			0
228	SS	700204	O	N								8.3			0
229	SS	700212	O	N								6.6			0
230	SS	700303	P	A											0
231	SS	700403	O	N,L								7.8			1
232	SS	701017	P	C											0
233	SS	701218	P,O	A,B,C,I											3
234	SS	701225	P	A,B,C											5
235	SS,GB	701227,701227	P,O	A,B,C,I,L,M,W	9.1	6.7	7.3					7.7	10.8		5,4
236	SS,GB	710106,710107	P	A,B,C,A1,I	9.8	10.4	6.7								3,2
237	SS,GB	710116,710118	P,O	A1,S,M,B,C	13.4	10.4	5.8	11.8		13.6			11.0		5,5
238	SS	710130	O	N								7.9			2
239	SS	710209	O	N								8.7			1
240	GB	710224	O	I	5.8	5.8	3.0								0
241	SS	710305	P,O	A,B,C,I,M								10.4		13.3	4
242	EB	710328	O	I											2
243	GB	710421	O	W	9.1	5.5	7.0								0
244	GB	711003	O	W	7.0	10.4	6.1								2
245	SS	711114	P,O	A,B,C,I,L											3
246	EB	711125	O	I											2
247	EB	711128	O	I											1
248	GB	711207	O	W	11.0	8.5	6.7								1
249	SS	711225	P	A,B											3
250	GB	720102	P,O	A1,I,M	12.2	11.3	6.4			13.5	11.1				2
251	SS,GB	720104,720104	P,O	A,B,C,M,W	9.5	9.8	4.9						10.8		3,5
252	SS,GB	720108,720109	P,O	C,W	9.5	7.0	5.2								1,4
253	SS	720114	O	N,L								6.4			2
254	GB	720120	O	W	9.5	6.4	3.7								2
255	SS	720123	P,O	A,I											2
256	GB	720204	O	W,M	9.5	9.5	5.2			12.3					0
257	SS,GB	720204,720207	P	A,B,A1	7.0	9.8	6.7					7.6			4,3
258	SS	720209	P	C											0

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	PEAK HS(M)-SS NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	TAR #
259	SS,GB	720215,720216	O	N,W	9.1	6.4	5.8					6.9			3,2
260	SS,GB	720219,720220	P,O	A,B,I,L,M,W	11.9	9.1	7.3			12.2		8.2	11.6		3,3
261	GB	720230	O	W,L	10.7	7.0	5.8								1
262	GB	720304	O	W	9.8	7.6	1.8								0
263	GB	720315	O	W,M	10.1	9.5	2.1			12.2					1
264	SS	720318	O	N								7.0			0
265	SS,GB	720327,720330	O	I,W	11.0	7.6	2.7								5,1
266	GB	720402	O	W	9.5	6.1	4.3								2
267	SS	720410	O	I											1
268	SS,GB	720418,720419	P,O	B,C,L,A1,I,M	12.2	7.9	7.3			13.6					4,3
269	SS	720510	O	I,L											0
270	EB	720904	O	I											HUR
271	SS	720911	O	I											1
272	EB	721007	O	I											2
273	SS	721020	O	I											0
274	SS	721106	O	N,M								7.7		9.9	0
275	EB	721115	O	I											2
276	SS	721119	P	C											0
277	SS	721123	O	I											4
278	SS	721127	O	N								7.5			2
279	SS,GB	721201,721202	O,P	I,M,A1,B1	10.4	9.1	5.8					6.3	10.9		4,5
280	GB	721208	P	A1,L	6.4	5.8	4.6								4
281	GB	721215	P	A1,B1,L,M	9.8	17.1	5.8			14.1					4
282	SS,GB	721217,721218	P,O	B,C,I,M,A1	9.5	7.6	5.8					6.8		10.1	4,3
283	SS	721223	O	N								6.8			0
284	GB	721229	O	W,M	10.7	12.2	5.2			12.8					4
285	SS	730103	P	A,B											2
286	GB	730104	O	W	9.5	9.5	5.8								1
287	SS	730107	P	B,C,M										13.7	4
288	SS	730114	O	N,L								7.5			1
289	GB	730114	O	W,L,M	16.5	8.2	4.0				10.6				1
290	GB	730119	O	W	8.2	16.5	6.4								4
291	SS	730121	P,O	C,I,M								6.7		10.0	3
292	GB	730126	O	W	8.5	11.9	3.0								0
293	SS,GB	730129,730131	O	N,W	7.9	11.9	6.7					6.3			3,0
294	SS	730203	P	A,B,C								7.7			5
295	GB	730205	O	W	10.4	8.5	4.9								3
296	SS	730212	O	N,M								7.0	13.7		3
297	SS,GB	730217,730218	O	I,W	7.6	9.5	4.9								4,0
298	SS,GB	730223,730223	P,O	A,B,L,W	11.0	11.6	4.9								2,4
299	SS	730228	O	N								7.6			0
300	SS	730301	O	N								7.4			2
301	SS,GB	730314,730315	O	M,I	9.5	14.6	3.4							9.9	4,2

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB SCWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	PEAK HS(M)-SS NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	TAR #
302	SS	730318	O	N								6.8			2
303	SS	730323	P,O	A,B,C,S,L,N								14.3	16.2	12.3	4
304	SS	730328	O	N								11.1			0
305	SS	730411	P	A											1
306	SS	730618	O	I,L											4
307	SS	730706	P	A											2
308	GB	731012	P	B1	7.0	9.5	6.7								0
309	SS,GB	731027,731028	O,P	I,L,N,A1,S	8.2	20.4	9.8	11.1				7.1		11.2	3,3
310	SS	731102	P,O	A,B,C,I,N								6.8		13.5	3
311	GB	731124	P,O	A1,I,L	10.4	14.3	7.9		5.8						1
312	SS	731129	O	N								6.5			1
313	SS	731217	O	N,M								7.3		11.5	0
314	SS	731222	O	M										11.7	2
315	SS,GB	731224,731227	P,O	C,W	8.8	10.7	3.7								1,1
316	SS	740102	P	A,B,C,L											2
317	GB	740104	P,O	A1,B1,I,L,N	11.9	18.6	8.5			15.0					4
318	SS	740108	P	C											3
319	GB	740109	P	A1,B1	9.5	9.1	6.7								4
320	GB	740116	O	W	9.8	7.3	4.9								1
321	GB	740119	P	A1	9.8	7.7	5.8								1
322	SS,GB	740120,740121	P,O	B,C,I,W	8.2	9.8	6.1								3,3
323	GB	740128	O	W	11.3	14.0	4.0								0
324	SS	740202	P,O	A,B,C,I,L											4,5
325	SS,GB	740205,740207	P,O	A,B,C,S,L,N,A1	10.4	10.1	5.2			12.3		7.5	11.4	9.9	5,1
326	SS	740218	P,O	A,B,C,I,L,N								7.4	11.5		4
327	SS,GB	740224,740224	P,O	W,A,B,C,I	9.5	6.7	4.9					8.3			3,0
328	SS,GB	740305,740306	O	N,M,W	12.2	8.8	4.9					7.7	10.3	10.0	0,0
329	SS,GB	740311,740312	P,O	A1,S,L,N,A,B,C	14.6	10.1	10.1	10.4		15.1			10.7		5,5
330	EB	740317	O	I											3
331	SS,GB	740327,740329	P,O	A,B,C,I,L,A1,N	14.0	10.4	9.5			15.2		7.6			5,5
332	EB	740331	O	I											0
333	SS	740406	O	N								7.2			0
334	SS	740423	O	N								6.2			0
335	SS	740528	P,O	B,C,I											0
336	GB	740707	O	W	7.6	9.8	5.8								0
337	SS	740908	O	I											2
338	SS,GB	740926,740928	P	A,A1,B1	5.8	5.5	4.9								0,2
339	SS	741020	O	I,L											5
340	SS,GB	741127,741128	O,P	I,A1	5.5	4.3	6.7								4,0
341	SS	741203	P,O	A,I								6.6			4
342	GB	741211	O	W	9.5	4.9	5.2								1
343	SS,GB	741215,741217	O,P	I,A1	8.2	-	6.7								4,3
344	GB	741220	P	A1	8.2	6.4	7.9								2

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	PEAK HS(M)-SS NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	TAR #
345	GB	741225	O	W	8.2	10.7	6.1								0
346	GB	741228	O	W	8.2	9.5	5.8								0
347	GB	750103	O	W	9.8	7.0	6.7								2
348	SS	750108	P,O	A,B,C,I											3
349	SS,GB	750126,750127	O	N,W	11.6	8.5	6.1					9.2			2,0
350	SS,GB	750130,750131	O	N,W	9.8	9.5	5.5					8.7			3,5
351	GB	750205	O	W,L	9.1	7.9	5.8								5
352	GB	750209	O	W	9.8	10.4	6.1								2
353	SS	750210	P	A,B,C											3
354	SS,GB	750316,750317	P,O	A,B,C,N,A1,I	10.4	11.6	NA				11.5			10.5	1,1
355	SS	750320	O	N								8.4			0
356	SS,GB	750331,750331	O	N,W	9.5	5.5	0.0					6.1			3,3
357	SS	750404	O	I								8.4			2
358	SS,GB	750417,750418	O	I,N,W	9.5	6.4	6.1					7.8	10.5		2,1
359	SS	750420	O	N								7.8			0
360	GB	750502	P	A1	7.9	4.9	5.5								2
361	SS	750506	O	I											0
362	GB	750519	O	W		9.8	6.1								0
363	SS	750701	O	N								7.9			HUR
364	SS	750901	O	I											1
365	SS	750927	O	N								6.8			0
366	SS,GB	751008,751008	O,P	I,A1		6.7	7.9								4,2
367	SS	751031	O	I											1
368	SS	751218	O	I											3
369	SS	751223	O	N,M								7.2	11.9		2
370	SS	760118	P	B,C											1
371	SS	760122	P,O	A,I											5
372	SS	760203	P,O	C,I,L											3
373	SS	760223	P	A											2
374	EB	760310	P	I											0
375	SS,GB	760312,760313	P	A,A1			4.9								2,3
376	SS,GB	760314,760315	P	A,A1			5.5								3,3
377	SS,GB	760317,760318	P,O	A,C,I,L,A1,S			10.1	10.3							5,4
378	SS	760410	P,O	A,C,I											2
379	GB	760422	P	A1			6.4								2
380	GB	760614	O	I,L			7.0								2
381	SS	760820	P	A											HUR
382	SS,GB	761019,761020	P,O	C,I,A1			8.2								5,4
383	SS	761021	O	I											2
384	SS,GB	761107,761107	O	I			6.7								5,1
385	SS,GB	761109,761110	P,O	A,C,I,A1			7.0								5,3
386	SS	761119	O	I,L											4
387	SS,GB	761209,761210	O	I			6.7								0,4

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
388	SS,GB	761211,761212	O,P	I,A1			7.9								1,1
389	SS	761227	O	I											4
390	SS	761230	O	I											4
391	SS	770106	P,O	A,I											2
392	SS	770111	P,O	C,I,L											3
393	SS	770118	O	I											4
394	GB	770121	O,P	A1,S			9.1	12.1							5
395	SS,GB	770207,770207	P,O	C,I,L			6.7								5,4
396	SS	770317	P,O	A,I											0
397	SS	770404	P,O	C,I											1
398	SS	770510	O	I											0
399	SS	770915	O	I											1
400	SS	771207	P,O	C,I											5
401	SS	771210	P	A,C,L											3
402	GB	771219	P	A1,L			7.6								1
403	GB	780104	O	I,L			10.1								3
404	SS	780110	P,O	B,C											4
405	SS	780114	P	A											0
406	SS	780207	O	I											3
407	SS,GB	780213,780217	P,O	B,L			8.2								4,5
408	GB	780304	P,O	A1,S,L			12.8	10.2							5
409	SS	780305	P,O	A,B,C,I,L											5
410	SS	780412	O	I											1
411	SS	780429	O	I											2
412	GB	780911	O	W											4
413	GB	781130	P	A1			6.7								3
414	GB	781208	P	A1			6.1								0
415	SS,GB	781210,781212	P,O	A,B,C,I,A1			6.7								3,3
416	SS,GB	781217,781219	P,O	C,I,L			7.3								2,2
417	SS,GB	781222,781223	O	I			6.4								4,4
418	SS	781225	P,O	B,I											3
419	SS	790115	P	B											2
420	SS	790119	P,O	A,B,I											5
421	SS	790206	P	B,C,L											1
422	SS	790218	P	B,C											1
423	SS	790312	P	A,B,C											4
424	SS	790706	O	I											3
425	SS	791008	P	B											4
426	GB	791118	P	B1,L			7.9								4
427	GB	791125	P	B1			6.7								2
428	SS,GB	791209,791211	P	B,A1			7.9								2,1
429	SS	791218	P,O	B,C,I											4
430	SS	791227	P,O	A,B,C,I											5

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
431	GB	800104	O	S				8.9							4
432	SS	800124	P,O	A,I,L											5
433	SS,GB	800208,800209	O,P	I,A1,B1											4,3
434	SS,GB	800211,800212	O,P	I,L,B1,L											4,4
435	GB	800227	P	B1											4
436	SS	800312	O	I											2
437	SS	800315	O	I											0
438	SS	800405	O	I											1
439	SS	800423	O	I											0
440	SS	801026	O	I											3
441	GB	801118	O	I					8.2						4
442	SS,GB	801119,801120	P,O	A,B,C,I					8.2						5,5
443	SS	801122	P,O	B,C,I											5
444	GB	801129	P	A1,B1											1
445	SS	801216	P	C											4
446	SS	810103	O	I,L											4
447	SS	810111	P,O	B,I,L											5
448	SS	810113	P	C											1
449	EB	810118	O	I											3
450	SS	810203	O	I											2
451	SS	810307	P,O	C,I											5
452	SS	810315	O	I											2
453	SS	810317	O	I											5
454	SS	810321	P,O	B,C,I											4
455	GB	810401	P	A1,B1											4
456	SS	810403	O	I											1
457	SS	810423	O	I											0
458	SS	810907	O	I											HUR
459	SS	810920	O	I											0
460	GB	810926	P	A1											2
461	GB	811031	P,O	A1,B1,I					7.5						0
462	SS	811126	O	I											4
463	EB,SS	811207,811207	O	I											5,2
464	SS,GB	811217,811218	O,P	S,A1											2,0
465	SS,GB	811230,820101	P,O	A1,I,B1,C					8.2						5,4
466	SS	820105	P	C											2
467	SS,GB	820116,820117	P,O	A1,B1,S,L,C				11.4							5,5
468	SS,GB	820118,820119	P,O	C,A1,B1,I					8.7						5,3
469	GB	820122	O	I					7.2						0
470	SS	820124	O	I											4
471	SS	820128	O	I											0
472	GB	820202	O	S				9.2							2
473	GB	820207	O	I					7.2						5

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB SOWM	PEAK HS(M)-GB ARMY	PEAK HS(M)-GB METOC	PEAK HS(M)-GB OWI	PEAK HS(M)-GB MEDS	PEAK HS(M)-GB SOWM (ESRF)	PEAK HS(M)-GB ARMY (ESRF)	PEAK HS(M)-SS NAVY (GP 263-2)	PEAK HS(M)-SS SOWM (ESRF)	PEAK HS(M)-SS ARMY (ESRF)	TAR #
474	SS,GB	820214,820215	P,O	A1,B1,S,L,A,C				13.4							5,5
475	SS,GB	820407,820410	O,P	I,A1,B1,L											5,0
476	SS	820412	O,P	I,L,A1											4
477	SS	821003	P	A											0
478	SS	821116	O	I											3
479	GB	821209	P,O	A1,B1,S,L				8.6							5
480	SS	821213	O	I											0
481	SS	821220	O	I											0
482	SS	821227	O	I											3
483	SS,GB	830107,830107	O,P	I,L,A1											3,4
484	SS	830116	O	I											0
485	SS	830206	O	I											1
486	SS	830208	P	B,C											2
487	SS,GB	830213,830214	P,O	A,B,C,A1,B1,I,L											2,2
488	SS,GB	830216,830217	P,O	A1,B1,I,L					11.5						1,5
489	GB	830224	P	A1											3
490	SS,GB	830227,830228	P,O	B,C,I,A1,B1				9.2							4,1
491	SS,GB	830304,830308	P,O	C,A1,S,L,B1											3,3
492	SS	830712	O	I											0
493	SS	831026	P,O	A,B,C,I											5
494	GB	831104	P	A1,B1											0
495	SS,GB	831126,831128	P,O	C,A1,B1,S				8.8							5,0
496	GB	831201	O	S				6.7							0
497	GB	831205	P,O	A1,B1,I					7.2						1
498	SS	831208	P,O	C,I											3
499	GB	831220	P,O	A1,B1,S,L				11.2							3
500	GB	831226	O	S,L				8.8							4
501	GB	840127	P,O	A1,I					9.5						4
502	SS	840201	P,O	B,S											3
503	SS,GB	840310,840311	P,O	B,I,A1											5,2
504	EB	840314	O	I											0
505	GB	840329	O	I					6.5						2
506	SS	840330	P,O	A,B,C,I											3
507	SS	840406	O	I											0
508	GB	840423	P	A1											0
509	GB	841116	P	A1											1
510	GB	841122	P	A1											3
511	GB	841227	P	A1											4
512	SS,GB	850106,850107	P	A1,B1,B,C											4,3
513	SS	850116	P	B,C											4
514	SS	850121	P	B											4
515	SS,GB	850128,850129	P,O	B,C,A1,B1,I				10.1							3,5
516	GB	850204	P	A1											4

TABLE A-2 (cont'd)

STORM#	AREA	STORM PEAK	COMPANY	SOURCE TYPE	PEAK HS(M)-GB							PEAK HS(M)-SS			TAR #
					SOWM	ARMY	METOC	OWI	MEDS	SOWM (ESRF)	ARMY (ESRF)	NAVY (GP 263-2)	SOWM (ESRF)	ARMY (ESRF)	
517	SS	850319	P	B,C											1
518	GB	850516	P	A1											4
519	GB	850930	P	A1,B1											2
520	GB	851116	P	A1											3
521	GB	851201	P	A1,B1											3
522	GB	851205	P	A1											1
523	GB	851216	P,O	A1,I,B1					10.8						4
524	GB	851220	P,O	A1,I,B1					11.5						2
525	SS,GB	851221,851223	P,O	B1,I											3,3
526	GB	860105	P,O	A1,I											2
527	SS	860107	P	C											5
528	GB	860116	P	A1											2
529	EB	860127	O	I											2
530	GB	860217	P	A1											1
531	GB	860312	P	A1											1
532	EB	860425	O	I											1

TABLE A-2 (cont'd)

NOTES:

P=MACLAREN PLANSEARCH I=OCEANWEATHERS' INITIAL LIST SS=SCOTIAN SHELF
O=OCEANWEATHER INC. S=STORMS HINDCASTED BY OCEANWEATHER GB=GRAND BANKS
EB=GEORGES BANK STORM NOT FOUND ON ORIGINAL SCOTIAN SHELF LIST HUR=HURRICANE OR TROPICAL STORM

A = USING DATABASE COADS CANADIAN SHIP OBS, NOAA BUOYS AND OWS
WITH FIRST DATASET PRECONDITION WINDS > 40 KNOTS
SECOND DATASET PRECONDITION WAVES > 10 METERS

B = USING DATABASE RIG SURFACE OBS AND REGULAR SYSTEM INPUT TAPES (AS IN A)
WITH FIRST DATASET PRECONDITION WINDS > 34 KNOTS
SECOND DATASET PRECONDITION WAVES > 6 METERS

C = AS IN A
WITH FIRST DATASET PRECONDITION WINDS > 34 KNOTS
SECOND DATASET PRECONDITION WAVES > 6 METERS

D = USING DATABASE SAMBRO AND LURCHER LIGHTSHIP STATIONS
WITH PRECONDITION WINDS > 34 KNOTS

N = WAVEHEIGHT ABOVE HS THRESHOLD OF 20 FT IN NAVY WAVE MODEL BUT
STORM NOT IN OTHER LISTS

L = CANADIAN CLIMATE CENTER REPORT NO. 84-13

M = CLIMATOLOGY OF SEVERE STORMS AFFECTING COASTAL AREAS
OF EASTERN CANADA - ERSF REPORT #020

A1 = AS IN A
WITH FIRST DATASET PRECONDITION WINDS > 40 KNOTS
SECOND DATASET PRECONDITION WAVES > 6 METERS

W = WAVEHEIGHT ABOVE HS THRESHOLD OF 30 FT IN SOWM,ARMY, OR METOC BUT
STORM NOT IN OTHER LISTS

B1 = USING RIG SURFACE OBS
FIRST DATASET PRECONDITION WINDS > 34 KNOTS
SECOND DATASET PRECONDITION WAVES > 6 METERS

APPENDIX B

GEORGES BANK TROPICAL CYCLONES

TABLE B-1

SELECTED TROPICAL CYCLONES AT GEORGES BANK

1938 - 1957

#	YYMM	DD - DD	STORM CLASS	DATE OF C.A.	AT GEORGES BANK			AT 35 DEG N		
					Po	Vf	Vmax	Po	Vf	Vmax
1	3809	10 - 22	H/ET	21/21Z	954	20	75	938	29	100
2	3810	23 - 24	ET	25/06Z	1000*	44	30	997*	40	35
3	4005	19 - 26	TS/DEP	26/00Z	997*	9	35	997*	5	35
4	4008	30 - 03	H	02/12Z	972*	21	70	972*	8	70
5	4009	10 - 19	H	16/18Z	972*	20	70	963*	8	80
6	4109	18 - 25	TS/DEP	25/18Z	1000*	7	30	978*	10	60
7	4209	18 - 24	ET	22/18Z	997*	13	35	994*	5	40
8	4210	13 - 18	TS/ET	18/18Z	997*	17	35	994*	8	40
9	4309	13 - 16	TS/ET	15/12Z	994*	19	40	990	16	45
10	4310	11 - 17	ET	17/18Z	994*	35	40	983*	27	55
11	4407	30 - 04	TS/DEP	04/06Z	997*	13	35	978*	16	60
12	4409	09 - 16	H/TS	15/03Z	957	28	78	948	16	90
13	4410	12 - 23	ET	21/18Z	996	22	45	996	18	35
14	4506	20 - 01	TS	27/15Z	983*	13	55	987*	11	50
15	4609	12 - 17	H/ET	15/06Z	975*	19	65	967*	18	75
16	5008A	11 - 22	H	21/03Z	967*	19	75	926*	14	115
17	5008D	30 - 16	H/ET	12/12Z	978*	18	60	958*	15	85
18	5202	02 - 04	ET	04/18Z	987*	33	50	987*	28	50
19	5308B	11 - 16	H/ET	15/12Z	967*	19	75	953*	11	90
20	5308C	28 - 09	H	07/15Z	972*	20	70	963	18	80
21	5310	03 - 10	ET	07/15Z	978*	18	60	987*	23	50
22	5408	25 - 31	H/ET	31/15Z	967	30	80	959	10	85
23	5409	02 - 14	H	11/18Z	947	29	80	956	15	105
24	5508	07 - 21	TS	19/18Z	1000	13	35	990	10	65
25	5509	10 - 23	H/TS	21/03Z	976	33	70	960	10	65
26	5608	09 - 19	H	18/00Z	975*	18	65	963*	17	75
27	5609	21 - 30	ET	28/18Z	994*	14	40	1000*	4	30

YYMM - year, month of storm
DD - DD - beginning and ending day of storm
STORM CLASS - storm type within area
H - hurricane SUB - subtropical storm
TS - tropical storm SUB DEP - subtropical depression
ET - extratropical DEP - depression
DATE OF C.A. - date of closest approach
Po - central pressure
* - estimated central pressure
Vf - forward storm velocity (knots)
Vmax - maximum wind speed (knots)

TABLE B-2
SELECTED TROPICAL CYCLONES AT GEORGES BANK
1957 - 1986

#	YYMM	DD - DD	STORM CLASS	DATE OF C.A.	AT GEORGES BANK			AT 35 DEG N		
					Po	Vf	Vmax	Po	Vf	Vmax
1	5808	08 - 17	ET	17/09Z	1003*	32	25	1003*	14	25
2	580	24 - 31	H	29/18Z	982	18	90	955	16	110
3	5907	05 - 12	TS	11/12Z	987*	21	50	1000*	8	30
4	5909	20 - 02	ET	01/18Z	1004	20	30	997	13	60
5	6007	28 - 31	TS	30/18Z	990*	26	45	987	21	50
6	6008	17 - 20	H/TS	20/09Z	967*	24	75	967	23	75
7	6008	29 - 13	H	12/21Z	967	36	85	960	17	90
8	6109	11 - 26	H/TS	22/12Z	990	9	45	948	10	120
9	6109	12 - 15	TS	15/06Z	997*	25	35	997*	15	35
10	6109	30 - 09	H/TS	08/18Z	972	11	70	932*	16	110
11	6110	15 - 22	TS	20/18Z	978	21	60	983*	31	55
12	6208	26 - 02	H/TS/ET	30/06Z	994	6	55	986	16	65
13	6209	29 - 08	H	07/09Z	978	24	70	968	18	95
14	6310	16 - 30	H	29/12Z	958	25	95	963	11	85
15	6408	31 - 15	ET	14/21Z	983*	30	55	998	16	50
16	6409	13 - 24	H	24/06Z	982	16	65	980	6	75
17	6606	04 - 14	ET	13/09Z	1000	15	50	994	8	60
18	6810	13 - 21	H	21/06Z	975*	34	65	984	20	70
19	6907	25 - 05	TS	03/18Z	1002	35	55	1006	18	40
20	6908	10 - 13	H	12/06Z	997	35	75	997	28	75
21	6909	05 - 10	H	09/20Z	979	37	115	986	21	85
22	7008	15 - 18	TS	18/12Z	992	33	55	1011	14	30
23	7107	04 - 07	TS	06/18Z	1000	19	55	1001	8	30
24	7108	10 - 17	H	15/18Z	977	16	75	992	16	55
25	7108	20 - 29	TS	28/12Z	997	25	45	989	19	55
26	7109	10 - 14	TS	14/12Z	997	23	50	996	15	50
27	7206	14 - 22	TS	22/18Z	980	17	55	988	14	40
28	7208	29 - 05	TS/ET	04/00Z	992	10	55	1004	4	50
29	7307	30 - 01	SUB DEP	01/12Z	1007	10	25	1005	14	35
30	7409	02 - 05	TS	05/00Z	1004	32	40	1005	18	45
31	7507	23 - 28	H	28/06Z	980	18	70	992	13	60
32	7608	06 - 10	H/TS	10/06Z	983	23	60	967	20	90
33	8111	12 - 17	SUB	17/00Z	994*	11	40	985	6	62
34	8206	17 - 20	SUB	20/06Z	988	33	60	992	20	60
35	8409	08 - 16	TS	15/18Z	1004	28	40	1000	8	40
36	8507	15 - 19	TS	18/11Z	998	20	60	1003	11	45
37	8508	11 - 20	ET	20/18Z	1014	10	20	1008	13	30
38	8509	16 - 01	H/ET	27/18Z	986	35	75	942	21	90
39	8509	21 - 24	TS/DEP	24/18Z	1002	12	40	996	9	45
40	8606	04 - 08	TS	08/12Z	1006	24	30	1002	12	40
41	8608	13 - 29	TS	19/12Z	1004	14	40	987	9	50

YYMM - year, month of storm
DD - DD - beginning and ending day of storm
STORM CLASS - storm type within area
H - hurricane
TS - tropical storm
ET - extratropical
SUB - subtropical storm
SUB DEP - subtropical depression
DEP - depression
DATE OF C.A. - date of closest approach
Po - central pressure
* - estimated central pressure
Vf - forward storm velocity (knots)
Vmax - maximum wind speed (knots)

TABLE B-3

SELECTED TROPICAL CYCLONES AT GEORGES BANK

#	YYMM	DD - DD	DATE	DATE OF C.A.	Po	Pf	Rmax	Vf	Vmax	H_s
1	3809	10 - 22	-	21/21Z	954	1010	35	20	43.88	10.97
2	4008	30 - 03	-	02/12Z	972	1016	33*	21	40.41	10.11
3	4009	10 - 19	-	16/18Z	972	1016	33*	20	39.93	9.98
4	4409	09 - 16	-	15/03Z	957	1029	33	28	52.63	13.16
5	4506	20 - 01	-	27/15Z	983	1017	33*	13	32.70	8.17
6	4609	12 - 17	-	15/06Z	975	1013	33*	19	37.22	9.31
7	5008	11 - 22	ABLE	21/03Z	967	1014	33*	19	40.49	10.12
8	5008	30 - 16	DOG	12/12Z	978	1016	50	18	36.07	9.02
9	5202	02 - 04	-	04/18Z	987	1011	33*	33	38.11	9.53
10	5308	11 - 16	BARBARA	15/12Z	967	1013	23	19	40.54	10.13
11	5308	26 - 09	CAROL	07/15Z	972	1016	33*	20	39.93	9.98
12	5310	03 - 10	-	07/15Z	978	1015	33*	18	36.34	9.09
13	5408	25 - 31	CAROL	31/15Z	967	1014	24	30	46.25	11.58
14	5409	02 - 14	EDNA	11/18Z	947	1018	18	29	53.42	13.38
15	5608	09 - 19	BETSY	10/00Z	975	1015	47	18	36.94	9.24
16	5808	24 - 31	DAISY	29/18Z	982	1013	50	18	33.24	8.31
17	5907	05 - 12	CINDY	11/12Z	987	1016	33*	21	34.52	8.63
18	6008	17 - 20	CLEO	20/09Z	967	1017	13	24	44.75	11.19
19	6008	29 - 13	DONNA	12/21Z	967	1014	48	36	48.26	12.06
20	6109	11 - 26	ESTER	22/12Z	990	1016	50	9	26.60	6.65
21	6109	30 - 09	FRANCES	08/18Z	972	1018	14	11	36.96	9.24
22	6110	15 - 22	GERDA	20/18Z	978	1015	33*	21	37.82	9.45
23	6209	29 - 08	DAISY	07/09Z	978	1013	33*	24	38.50	9.63
24	6310	16 - 30	GINNY	29/12Z	958	1014	18	25	47.00	11.75
25	6408	31 - 15	DORA	14/21Z	983	1014	33*	30	39.80	9.95
26	6409	13 - 24	GLADYS	24/06Z	982	1010	20	16	32.12	8.03
27	6810	13 - 21	GLADYS	21/06Z	975	1015	30	34	45.47	11.37
28	6909	05 - 10	GERDA	09/20Z	979	1016	30	37	42.36	10.59
29	7108	10 - 17	BETH	15/18Z	977	1018	48	16	36.29	9.07
30	7206	14 - 22	AGNES	22/18Z	980	1015	33*	17	35.06	8.77
31	7507	23 - 28	BLANCHE	28/06Z	980	1014	30	18	35.27	8.82
32	7608	06 - 10	BELLE	10/06Z	983	1018	18	23	38.60	9.65
33	8508	16 - 01	GLORIA	27/18Z	986	1013	35	35	40.42	10.11

YYMM - year, month of storm
DD - DD - beginning and ending day of storm
DATE OF C.A. - date of closest approach
Po - central pressure
Pf - peripheral pressure
Rmax - radius of maximum wind (n.m.)
* - average Rmax
Vf - forward storm velocity (knots)
Vmax - maximum wind speed (metres/second)
Hs - significant wave height (metres)

APPENDIX C

HINDCAST VERIFICATION RESULTS

Files containing verification data for each storm.

STORM 1 Total period - 82011300 to 82011900
Kinematic period - 82011412 to 82011712

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Grand Banks	134	Sedco 706	Nautilus C-92	90	46.856	48.749	3744	WR, WMO
	140	Z. Ugland	W Flying Foam L-23	93	47.053	48.747	3744	WR, WMO
	156	O. Ranger	Hibernia J-34	78	46.733	48.845	3744	WR, WMO
Scotian Shelf								

STORM 2 Total period - 82021200 to 82021700
Kinematic period - 82021400 to 82021600

STORM 3 Total period - 83021000 to 83021500
Kinematic period - 83021200 to 83021500

	MEDS #	Rig Name	site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Scotian Shelf	*142	R. Juneau	Venture B-52	20	44.020	59.636	3619	WR, WMO
	165	Z. Scotian	Arcadia J-16	55	44.096	59.533	3619	WR, WMO
	168	John Shaw	Bluenose G-47A	85	44.106	59.356	3619	, WMO

STORM 4 Total period - 83102400 to 83102800
Kinematic period - 83102418 to 83102612

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Scotian Shelf	133	Sedco 709	Glenelg J-48	77	43.628	60.107	3590	, WMO
	*165	Z. Scotian	Venture H-22	21	44.023	59.552	3590	, WMO
	166	Bowdrill1	St. Paul P-91	183	47.183	60.227	3764	WR, WMO
	167	Vinland	Uniacke G-72	160	44.191	59.686	3590	WR, WMO
	171	Bowdrill2	Glooscap C-63	99	43.203	62.177	3589	WR, WMO

STORM 5 Total period - 83112400 to 83113012
Kinematic period - 83112512 to 83112712 (SS)
Kinematic period - 83112800 to 83113000 (GB)

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Scotian Shelf	133	Sedco 709	Alma F-67	68	43.605	60.666	3590	, WMO
	*165	Z. Scotian	Venture H-22	21	44.023	59.552	3590	, WMO
	166	Bowdrill1	St. Paul P-91	183	47.183	60.227	3764	WR, WMO
	167	Vinland	Uniacke G-72	160	44.191	59.686	3619	WR, WMO
	171	Bowdrill2	Glooscap C-63	99	43.203	62.177	3589	WR, WMO
	189	G. Lab. 1	Louisbourg J-47	66	44.445	58.357	3620	WR, WMO

Grand Banks	134	Sedco 706	North Dana I-43	222	47.212	47.604	3745	WR
	168	John Shaw	Trave E-87	142	46.938	47.969	3745	WR
	169	W. Venture	Hibernia K-14	80	46.728	48.793	3744	WR
	185	Sedco 710	Terra Nova K-08	86	46.459	48.517	3715	WR

STORM 6

Total Period - 83121900 to 83122400
Kinematic Period - 83122112 to 83122312

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	(W)	Near Grid #	Source
Grand Banks	134	Sedco 706	North Dana I-43	222	47.212	47.604	3745	WR
	168	John Shaw	Trave E-87	142	46.938	47.969	3745	WR

STORM 7

Total period - 84012912 to 84020312
Kinematic period - 84013100 to 84020200

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	(W)	Near Grid #	Source
Scotian Shelf	133	Sedco 709	Alma F-67	68	43.605	60.666	3590	, WMO
	*165	Z. Scotian	Venture H-22	21	44.023	59.552	3619	, WMO
	166	Bowdrill1	Bonnet P-23	113	42.380	65.051	3528	, WMO
	167	Vinland	Uniacke G-72	160	44.191	59.686	3590	, WMO
	171	Bowdrill2	Chebucto K-90	101	43.657	59.712	3590	WR, WMO
	189	G. Lab. 1	Louisbourg J-47	66	44.445	58.357	3620	WR, WMO
	210	R.Gorilla1	South Griffin J-13	55	44.377	58.032	3620	WR, WMO

STORM 8

Total period - 85010400 to 85010900
Kinematic period - 85010500 to 85010800

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	(W)	Near Grid #	Source
Scotian Shelf	133	Sedco 709	Glenelg H-38	85	43.622	60.080	3590	WR, WMO
	*142	R. Juneau	West Venture C-62	19	44.025	59.667	3590	WMO
	*165	Z. Scotian	West Venture N-91	36	44.013	59.741	3590	WMO
	185	Sedco 710	Albatross B-13	1310	42.703	63.037	3528	WR, WMO
	189	G. Lab. 1	Citadel H-52	65	44.190	58.878	3620	WR, WMO
	*210	R.Gorilla1	Hesper P-52	44	44.698	57.880	3620	, WMO
Grand Banks	166	Bowdrill1	W. Ben Nevis B-75	128	46.584	48.433	3744	WR
	167	Vinland	Beothuk M-05	90	46.413	48.521	3715	WR
	168	John Shaw	Mara M-54	88	46.730	48.646	3744	WR, WMO
	171	Bowdrill2	Conquest K-09	133	47.143	48.262	3744	WR

STORM 9 Total period - 85012512 to 85013012
Kinematic period - 85012700 to 85012912

	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Grand Banks	166	Bowdrill1	W. Ben Nevis B-75	128	46.584	48.433	3744	WR
	168	John Shaw	Mara M-54	88	46.730	48.646	3744	WR, WMO
	171	Bowdrill2	Conquest K-09	133	47.143	48.262	3745	WR
	172	Bowdrill3	N. Ben Nevis P-93	91	46.714	48.476	3744	WR

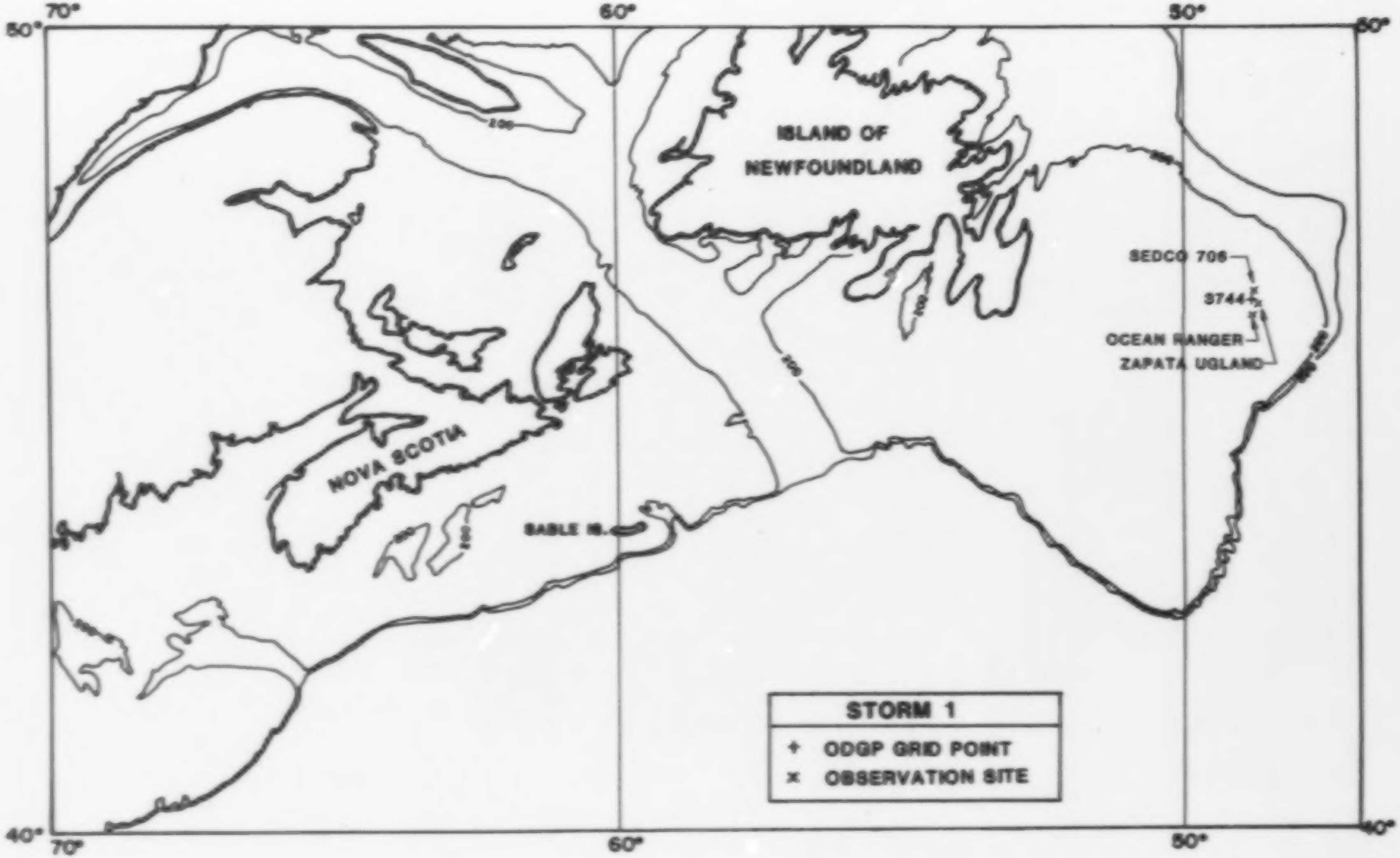
STORM 10 Total period - 85121512 to 85122112
Kinematic period - 85121812 to 85122012

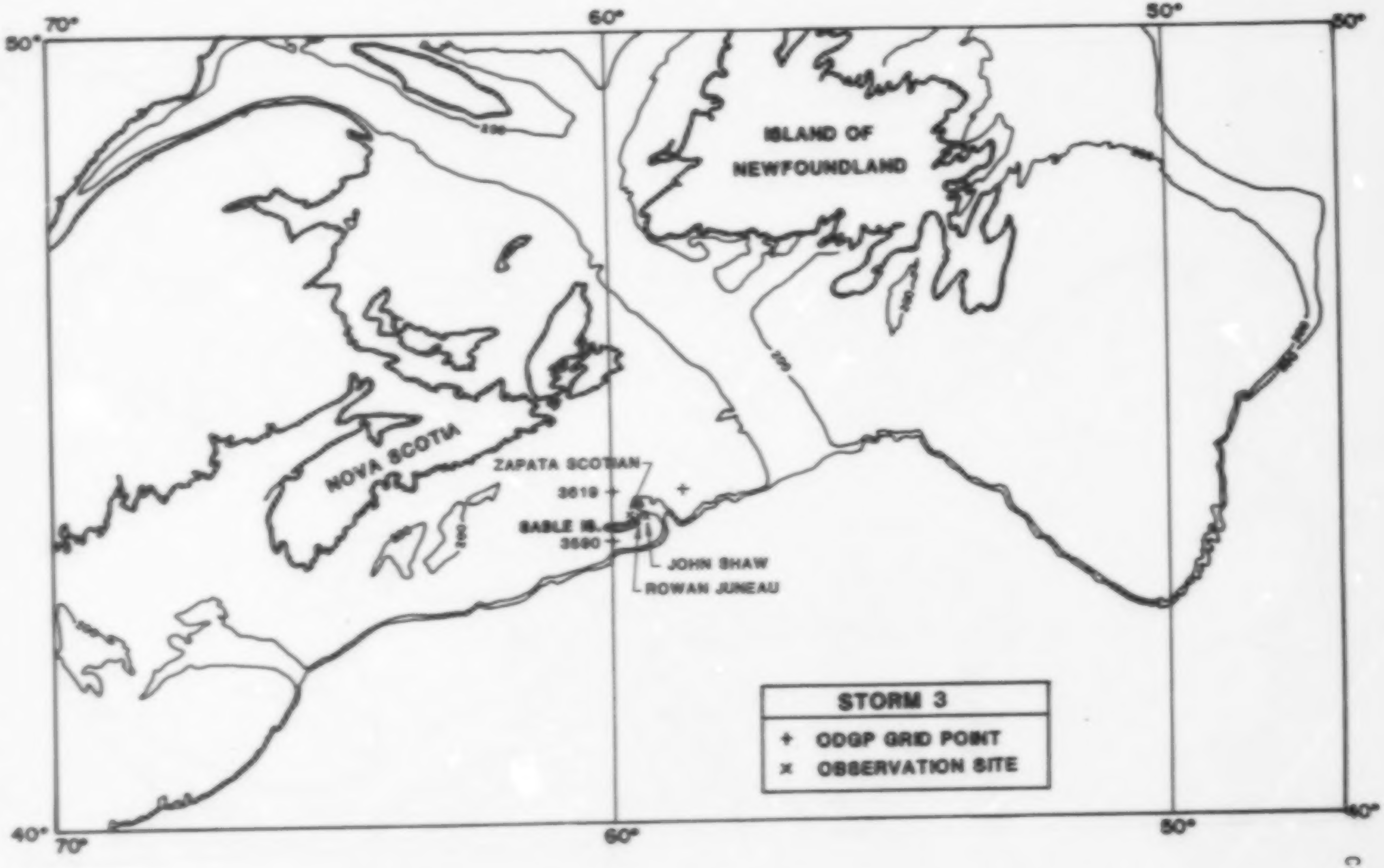
	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Grand Banks	167	Vinland	Terra Nova I-97	97	46.446	48.480	3715	, WMO
	171	Bowdrill2	Whiterose L-61	117	46.842	48.175	3744	WR,
	172	Bowdrill3	Panther P-52	194	47.032	47.629	3745	WR,
	185	Sedco 710	Gambo N-70	82	46.331	48.665	3715	, WMO

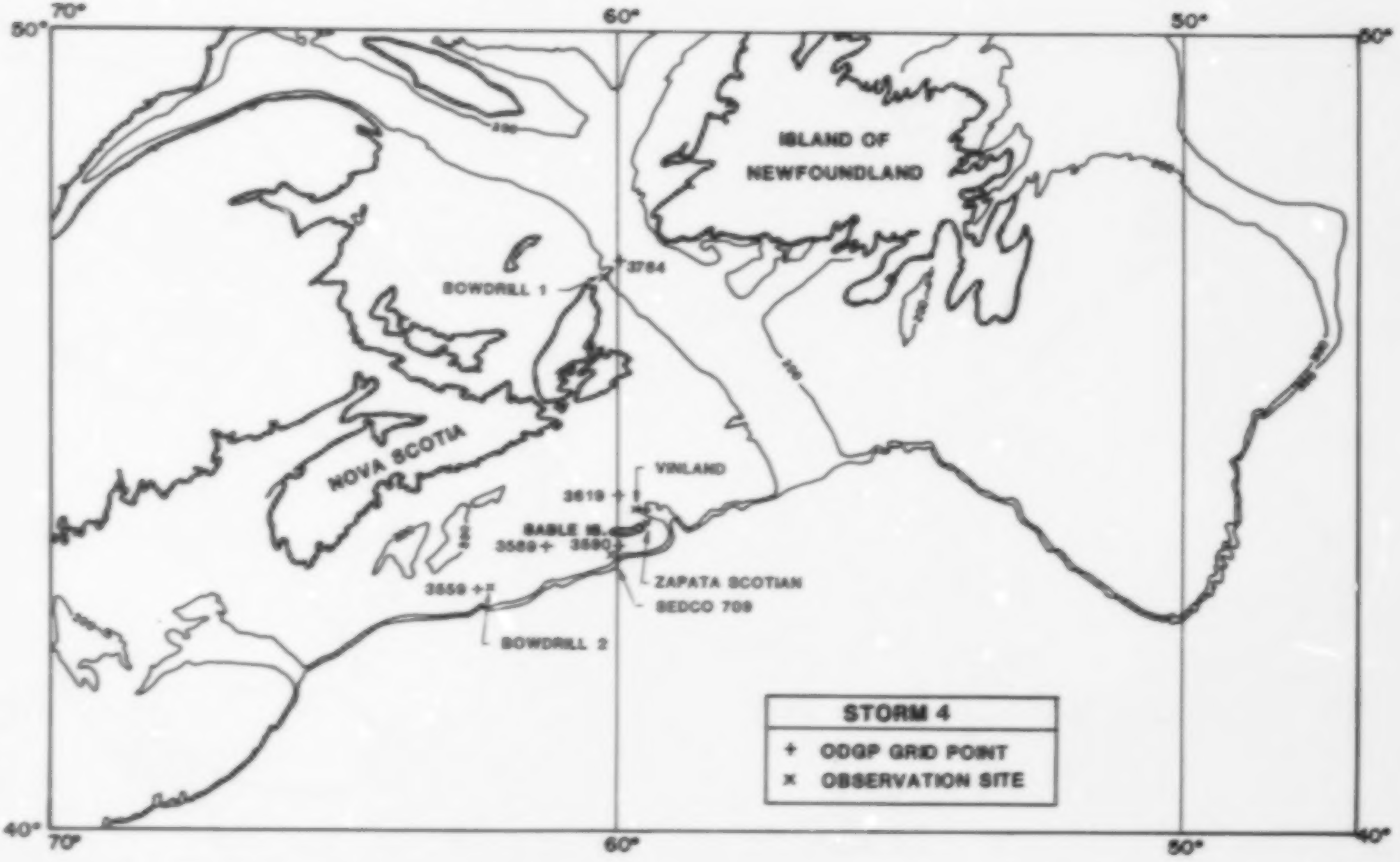
STORM 11 Total period - 86010212 to 86010612
Kinematic period - 86010400 to 86010600

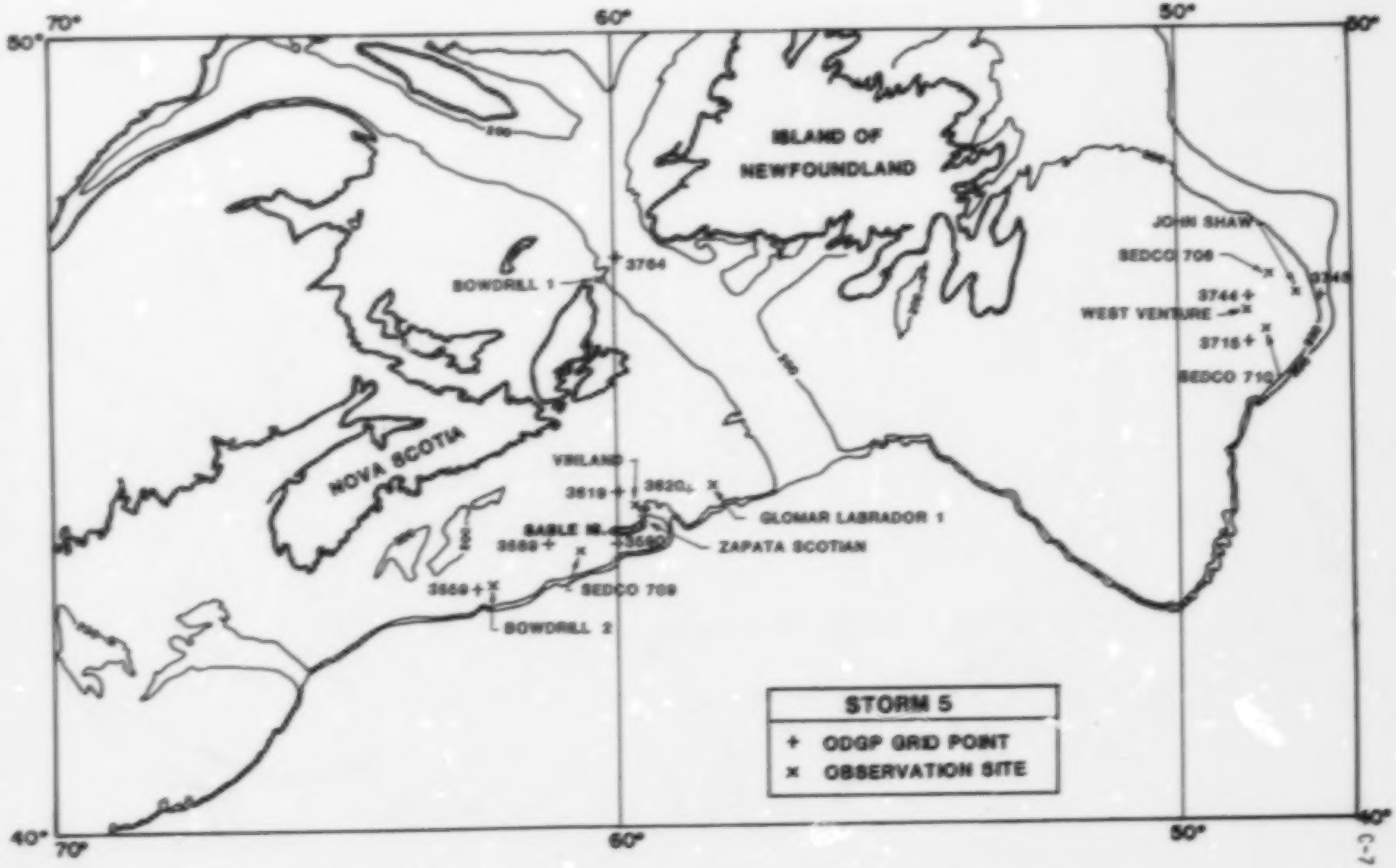
	MEDS #	Rig Name	Well site	Depth (m)	Location (N)	Location (W)	Near Grid #	Source
Grand Banks	167	Vinland	Terra Nova I-97	97	46.446	48.480	3715	, WMO
	171	Bowdrill2	Whiterose L-61	117	46.842	48.175	3744	WR,
	172	Bowdrill3	Panther P-52	194	47.032	47.629	3745	WR,

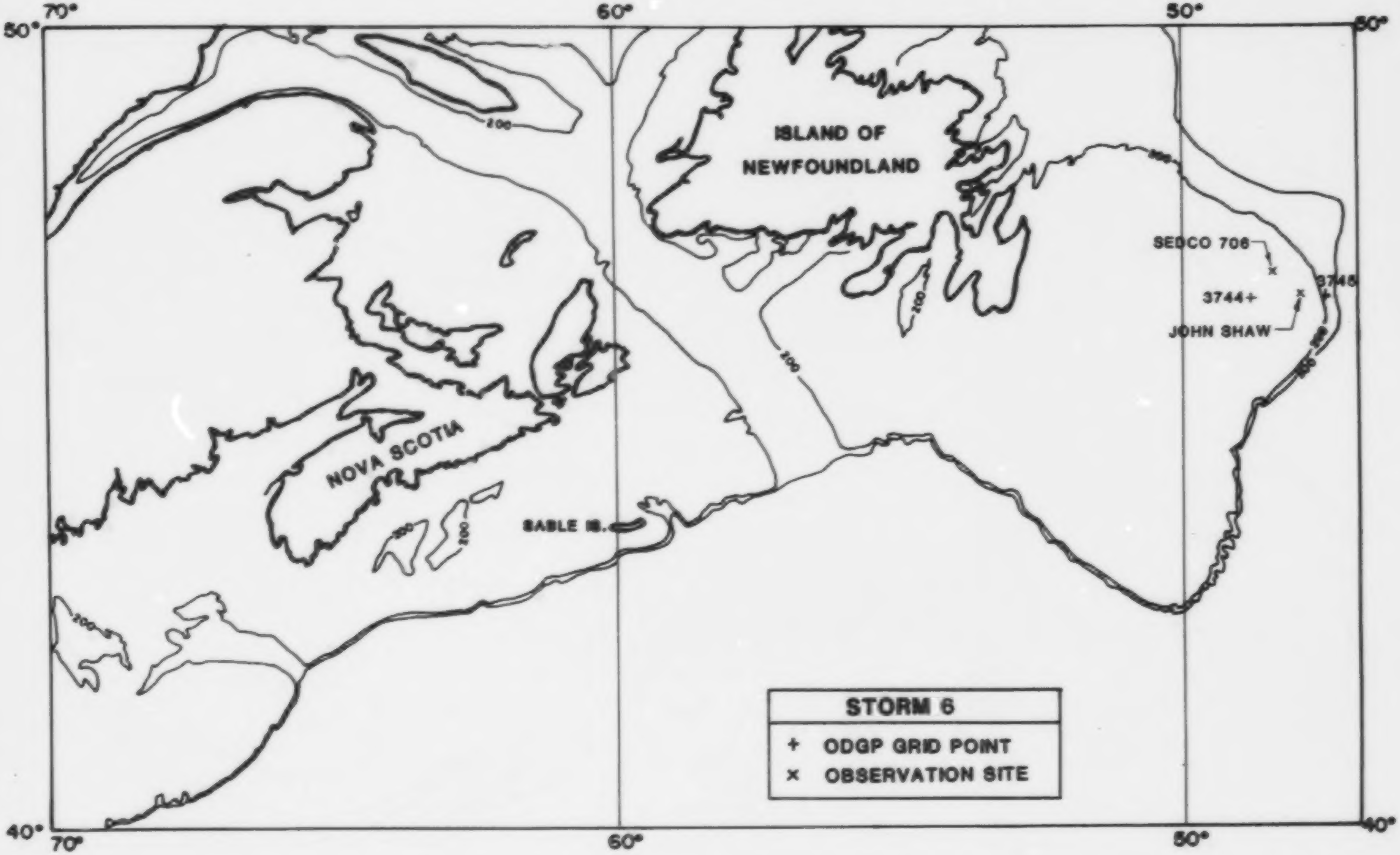
NOTE - Sites marked by * contain data at poor data locations, ie. data gaps and shallow water sites.
- WMO - Manmar data
- WR - Waverider data

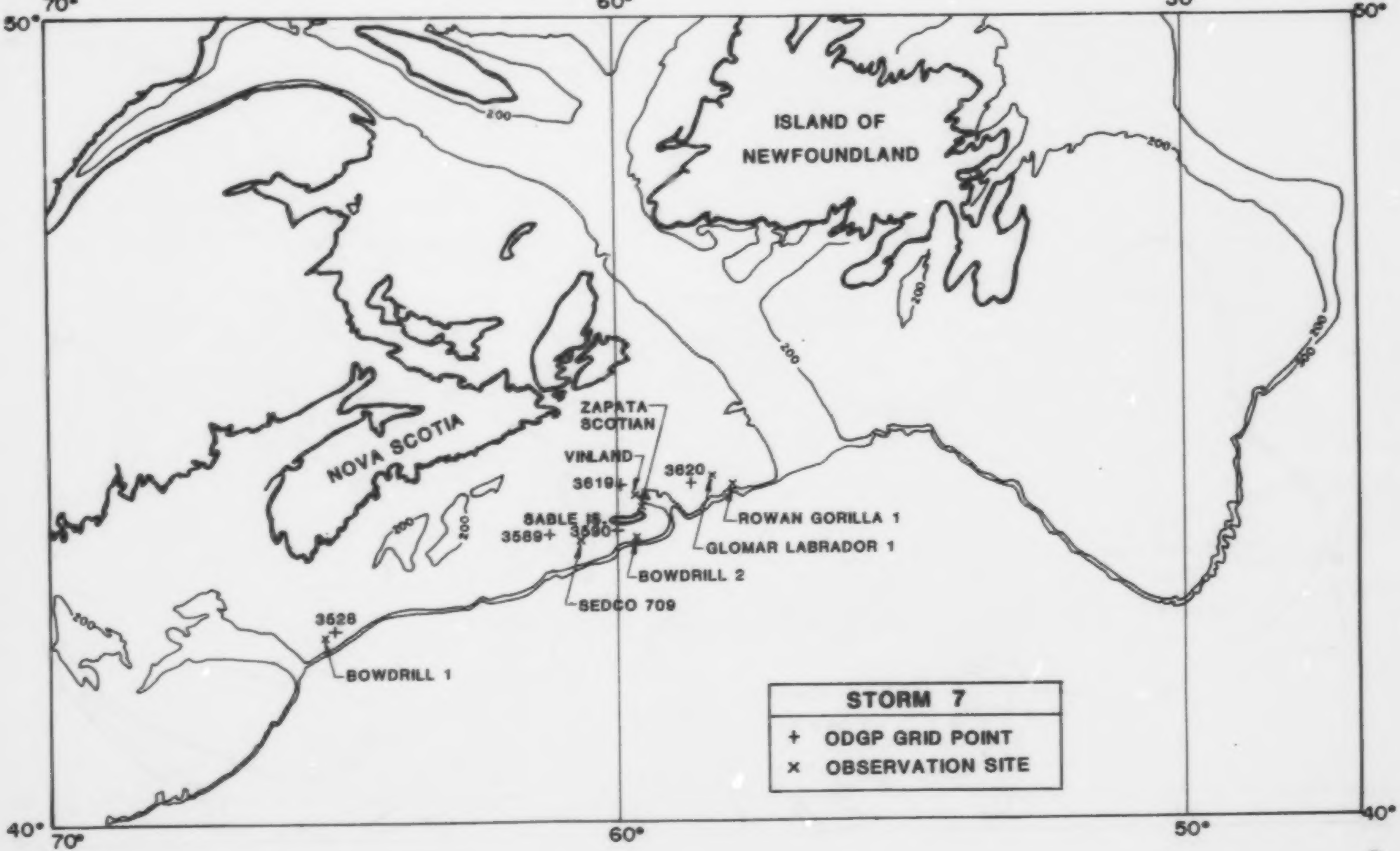

70°
60°
50°
50°
40°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
SABLE IS.
200
SEDCO 706
3744
OCEAN RANGER
ZAPATA UGLAND
STORM 1
+ ODGP GRID POINT
x OBSERVATION SITE

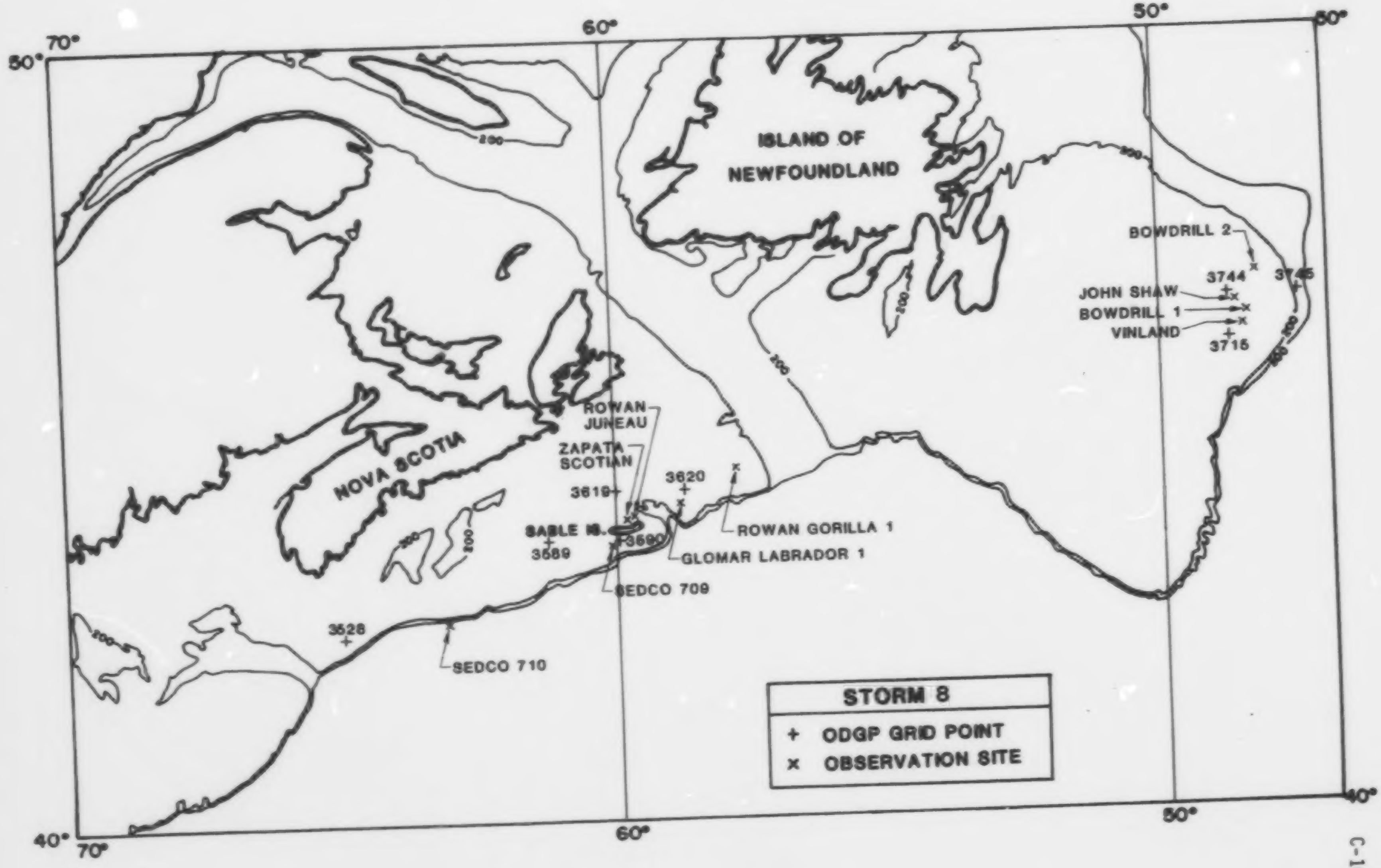

70°
60°
50°
40°
50°
40°
70°
60°
50°
40°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
ZAPATA SCOTIAN
3619 +
SABLE IS.
3590 +
JOHN SHAW
ROWAN JUNEAU
200
STORM 3
+ ODGP GRID POINT
x OBSERVATION SITE

70°
60°
50°
50°
50°
40°
40°
70°
60°
50°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
BOWDRILL 1
3764
200
VINLAND
3619
SABLE IS.
3589
3590
ZAPATA SCOTIAN
SEDCO 709
3559
BOWDRILL 2
STORM 4
+ ODGP GRID POINT
× OBSERVATION SITE

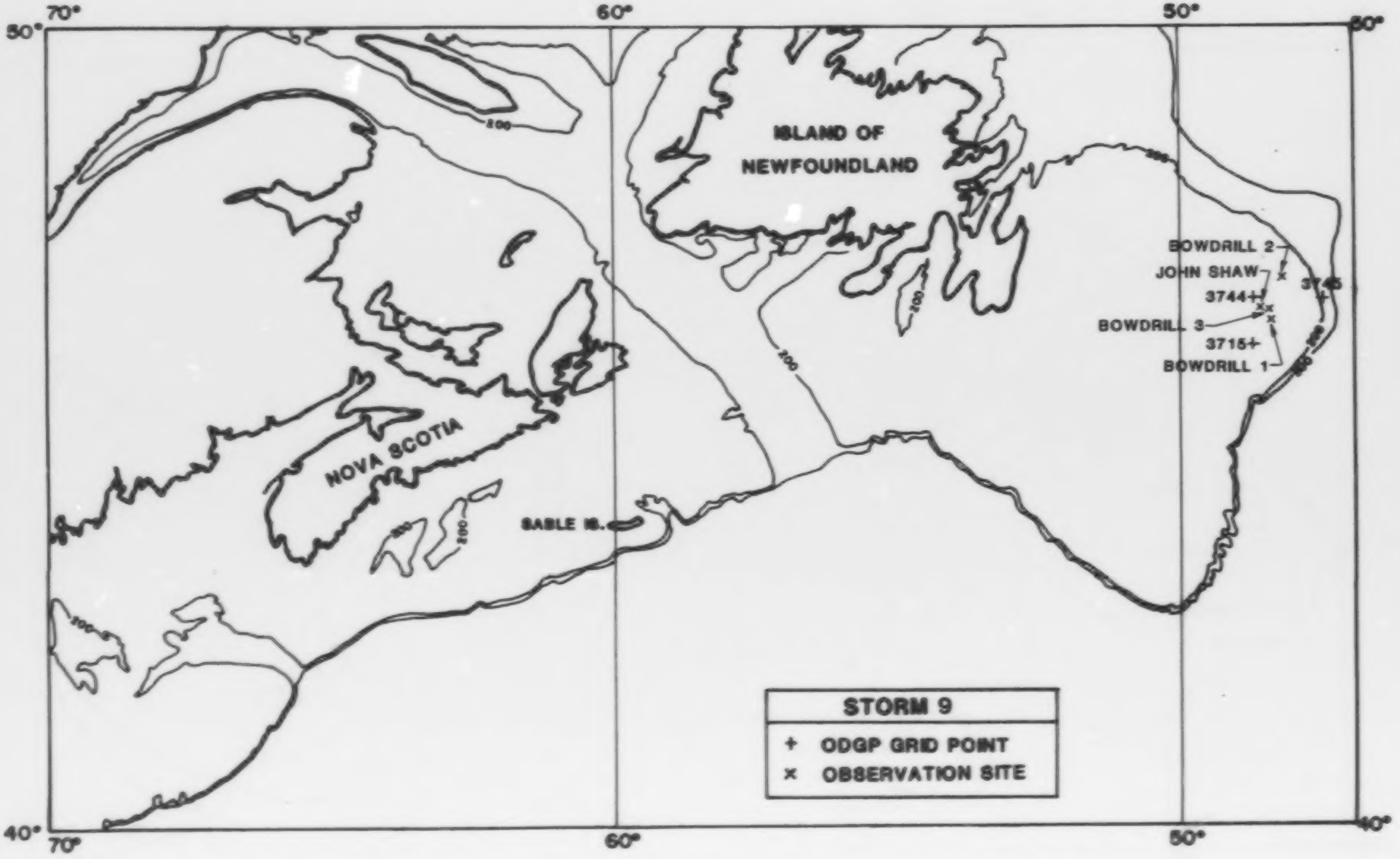

70°
60°
50°
50°
40°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
JOHN SHAW
SEDCO 706
3746
3744 +
WEST VENTURE
3716 +
SEDCO 710
3764
BOWDRILL 1
VINLAND
3619 +
3620
GLOMAR LABRADOR 1
SABLE IS.
3589 +
3590
ZAPATA SCOTIAN
SEDCO 709
3559 +
BOWDRILL 2
200
STORM 5
+ ODGP GRID POINT
× OBSERVATION SITE

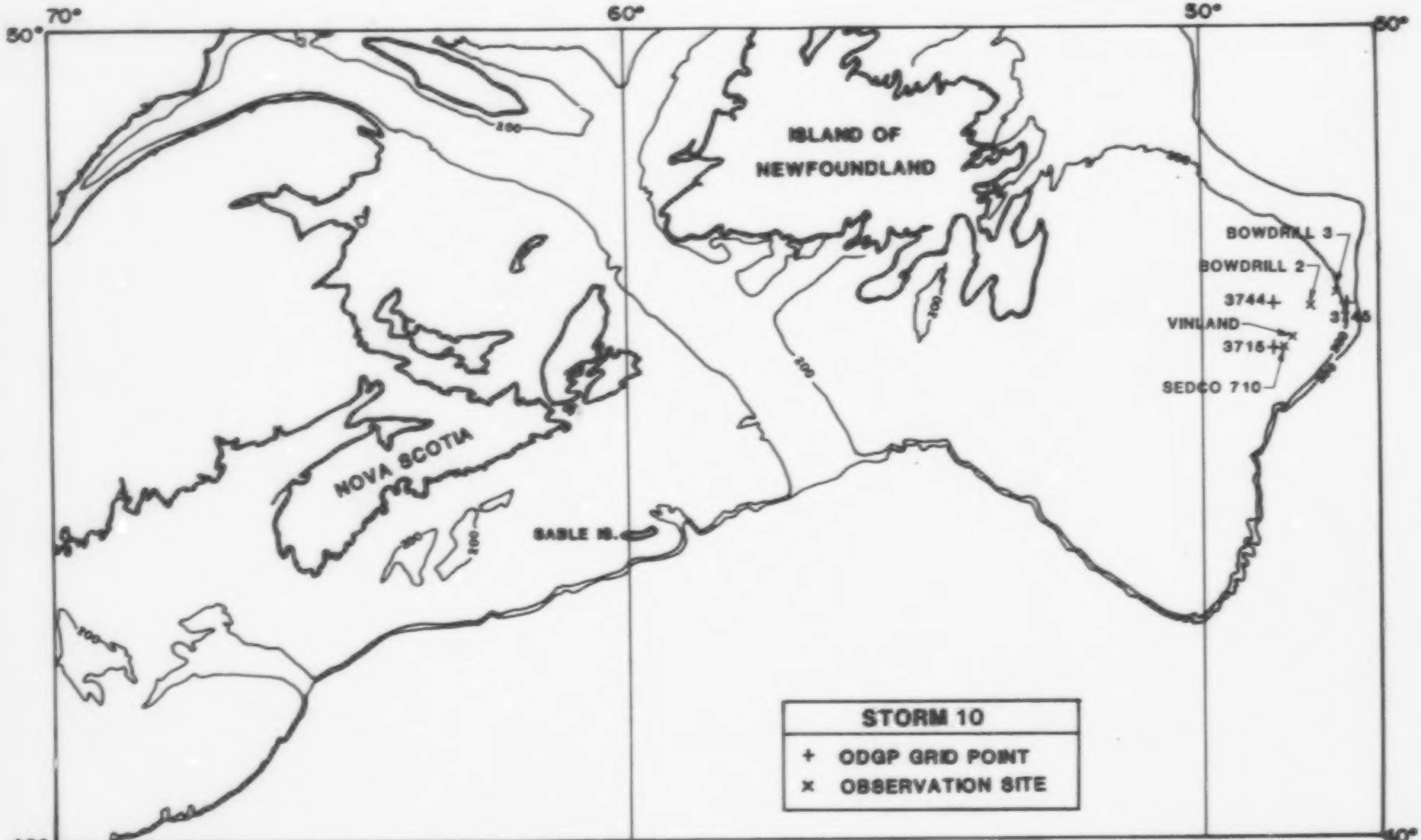
70°
60°
50°
50°
40°
70°
60°
50°
50°
40°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
SABLE IS.
200
200
200
200
200
200
200
SEDCO 706
3744+
3745
JOHN SHAW
STORM 6
+ ODGP GRID POINT
× OBSERVATION SITE


70°
60°
50°
50°
40°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
200
ZAPATA SCOTIAN
VINLAND
3619+
3620
SABLE IS.
3589+
3590
ROWAN GORILLA 1
GLOMAR LABRADOR 1
BOWDRILL 2
SEDCO 709
3528
BOWDRILL 1
STORM 7
+ ODGP GRID POINT
× OBSERVATION SITE



70°
50°
60°
50°
50°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
200
200
200
200
200
200
200
BOWDRILL 2
3744
3745
JOHN SHAW
BOWDRILL 1
VINLAND
3715
ROWAN JUNEAU
ZAPATA SCOTIAN
3620
3619
SABLE IS.
3589
3590
ROWAN GORILLA 1
GLOMAR LABRADOR 1
SEDCO 709
3528
SEDCO 710
STORM 8
+ ODGP GRID POINT
x OBSERVATION SITE
40°
70°
60°
50°
40°


70°
60°
50°
50°
40°
ISLAND OF
NEWFOUNDLAND
NOVA SCOTIA
SABLE IS.
200
BOWDRILL 2
JOHN SHAW
3744+
BOWDRILL 3
3715+
BOWDRILL 1
3745
STORM 9
+ ODGP GRID POINT
x OBSERVATION SITE

70°
60°
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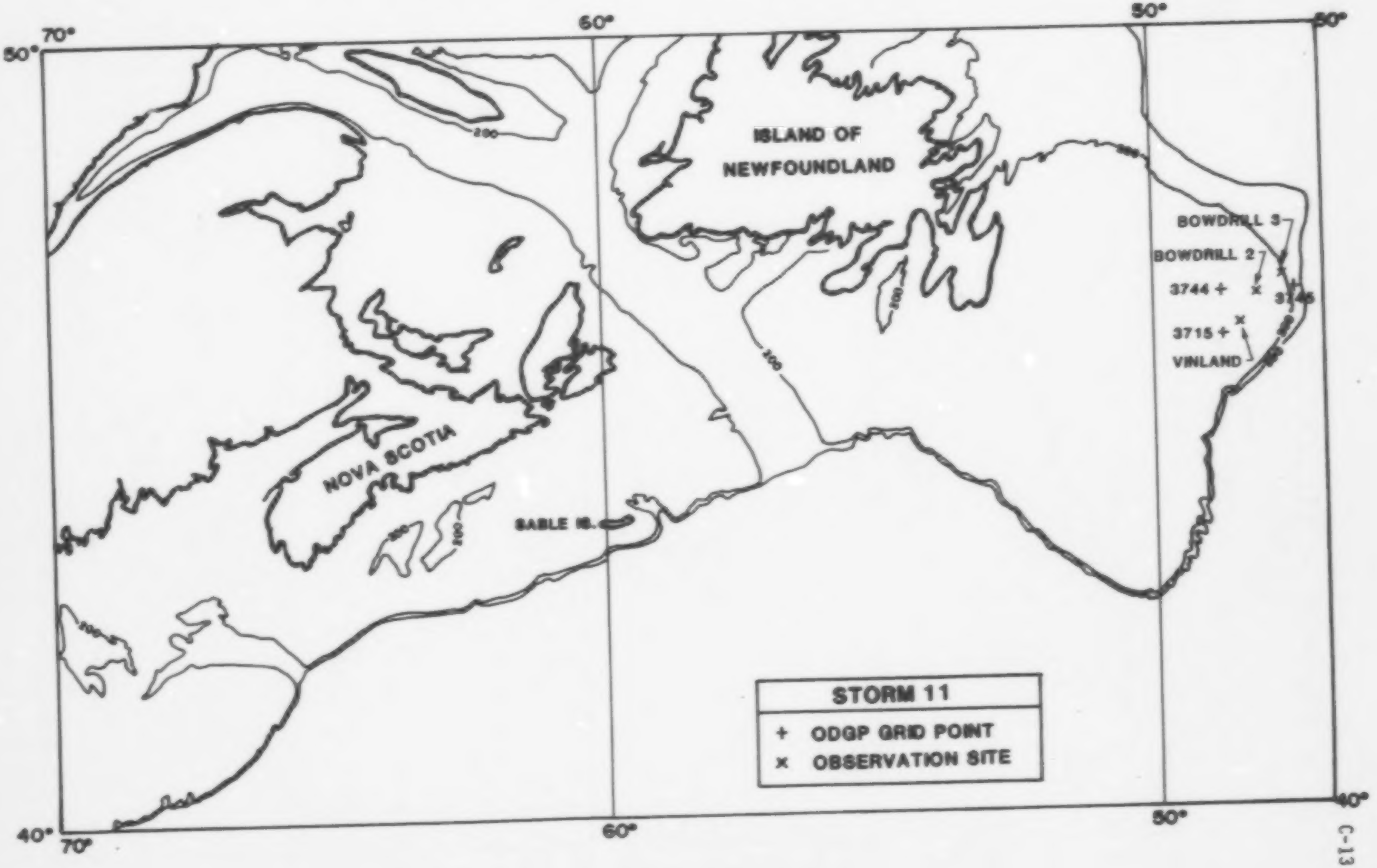
40°
40°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
SABLE IS.
BOWDRILL 3
BOWDRILL 2
3744
3745
VINLAND
3715
SEDCO 710
200
STORM 10
+ ODGP GRID POINT
× OBSERVATION SITE


70°
60°
50°
40°
50°
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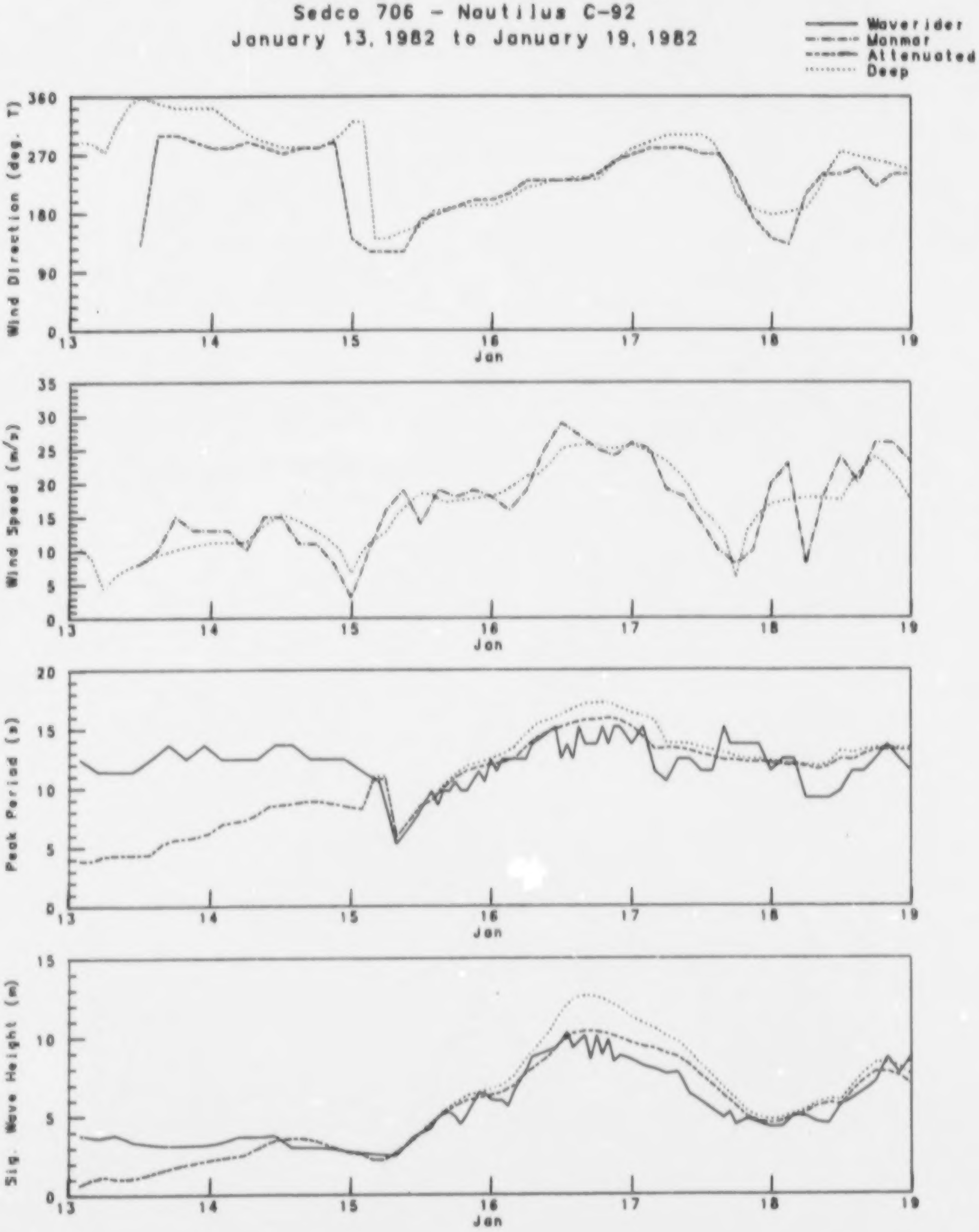
70°
60°
50°
ISLAND OF NEWFOUNDLAND
NOVA SCOTIA
SABLE IS.
200
BOWDRILL 3
BOWDRILL 2
3744 +
3745
3715 +
VINLAND
STORM 11
+ ODGP GRID POINT
x OBSERVATION SITE

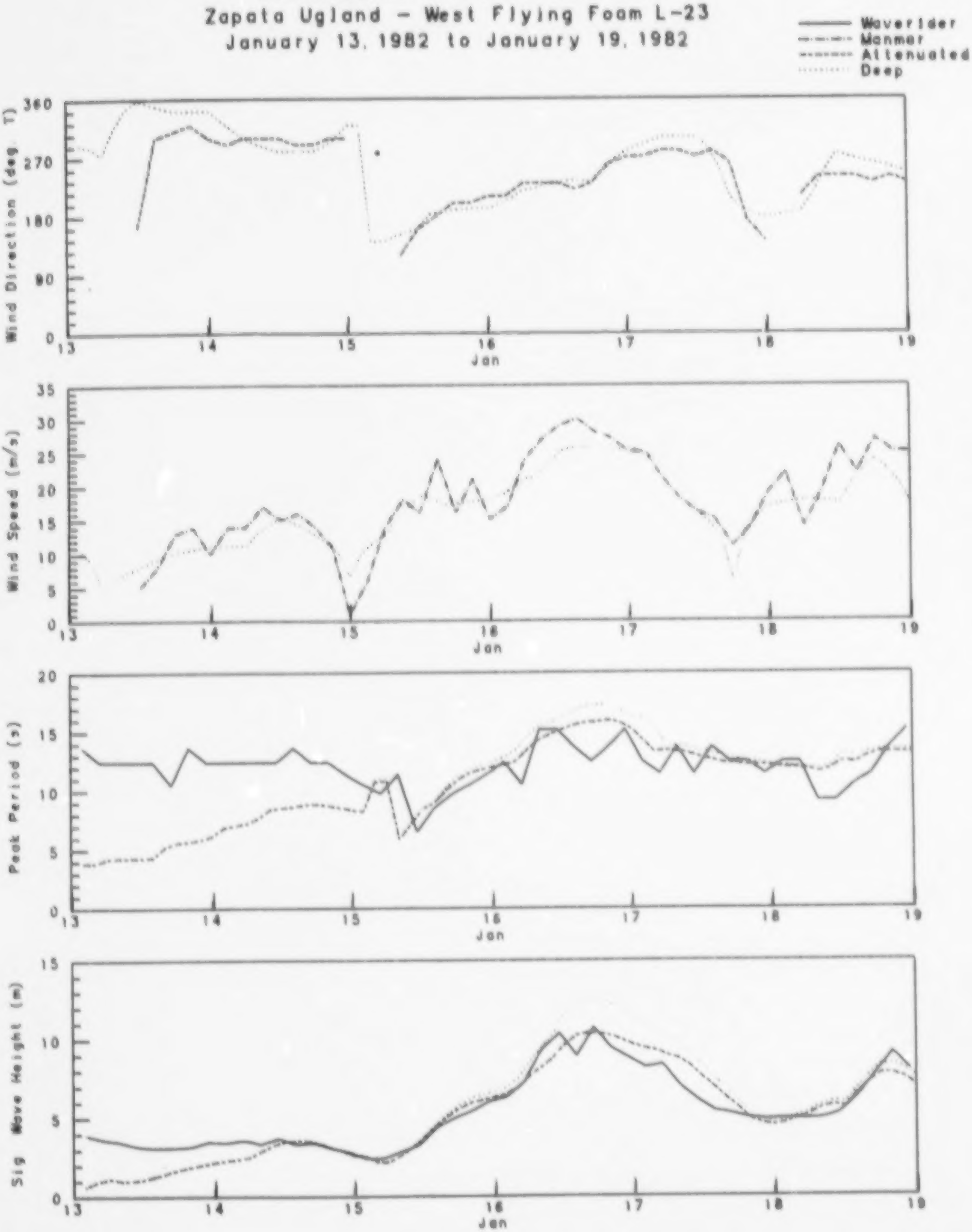
WIND/WAVE VERIFICATION FOR STORM 1

Grand Banks - Grid Point 3744
Sedco 706 - Nautilus C-92
January 13, 1982 to January 19, 1982



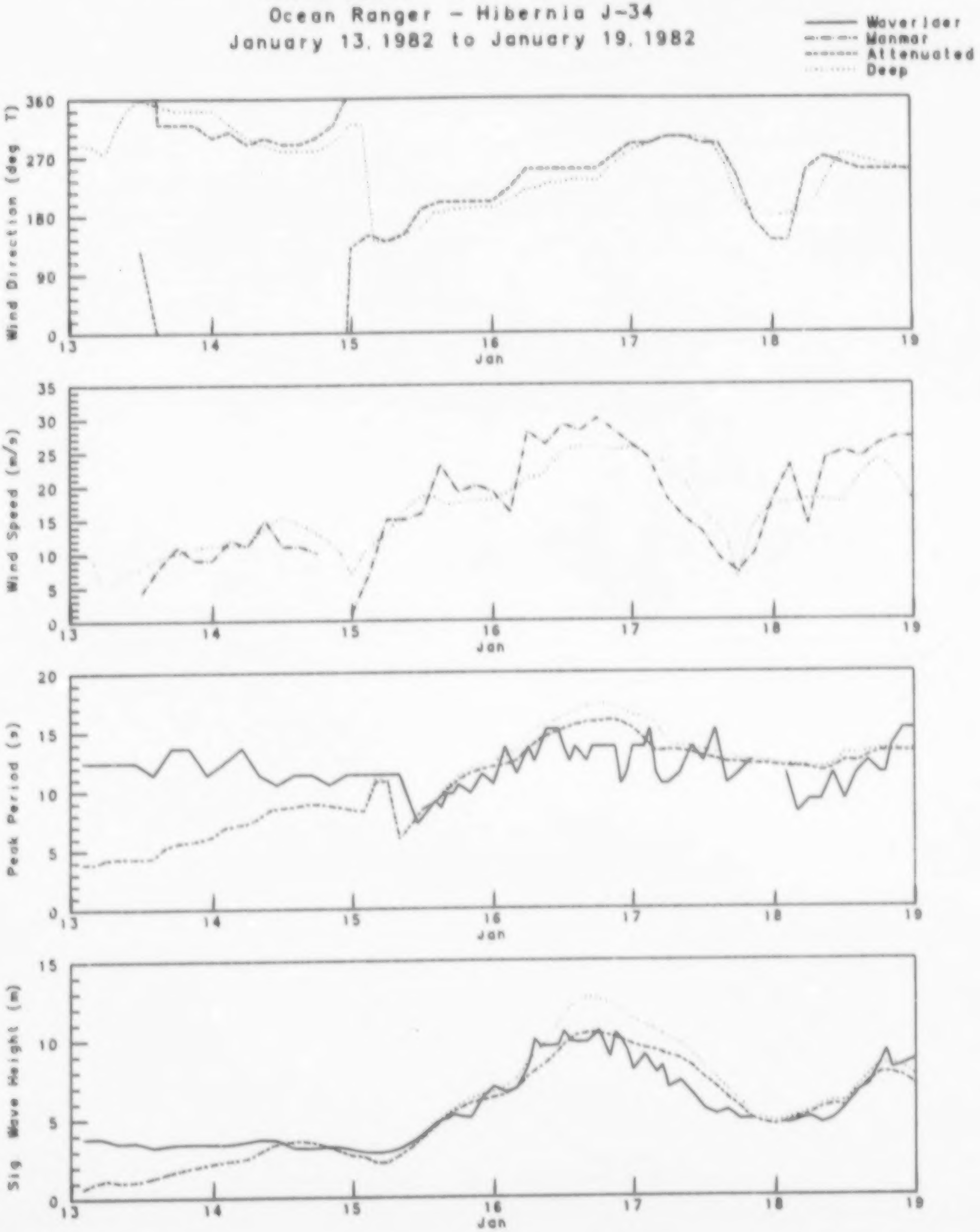
WIND/WAVE VERIFICATION FOR STORM 1

Grand Banks - Grid Point 3744
Zapata Ugland - West Flying Foam L-23
January 13, 1982 to January 19, 1982



WIND/WAVE VERIFICATION FOR STORM 1

Grand Banks - Grid Point 3744
Ocean Ranger - Hibernia J-34
January 13, 1982 to January 19, 1982

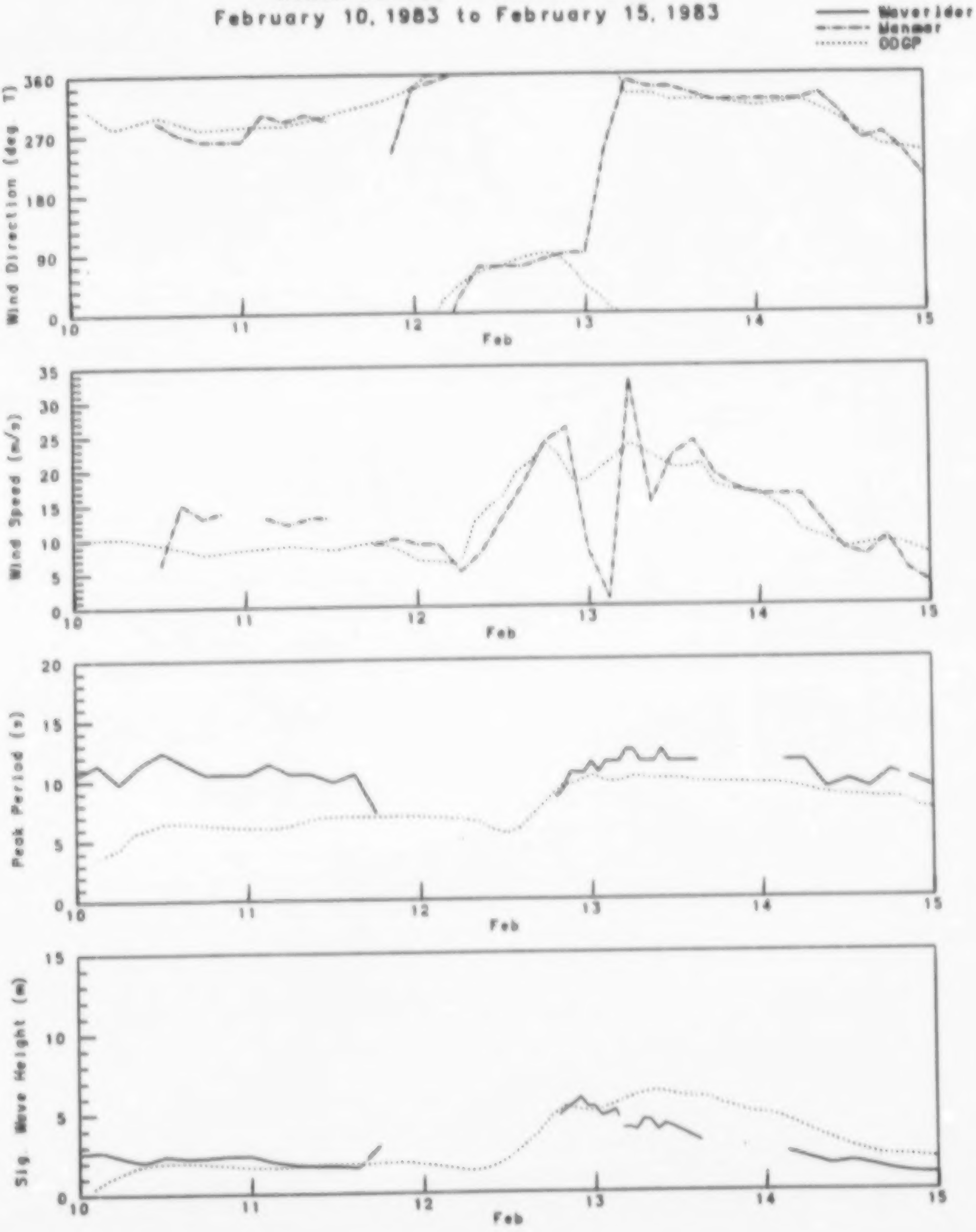


WIND/WAVE VERIFICATION FOR STORM 3

Scotian Shelf - Grid Point 3619

Rowan Juneau - Venture B-52

February 10, 1983 to February 15, 1983

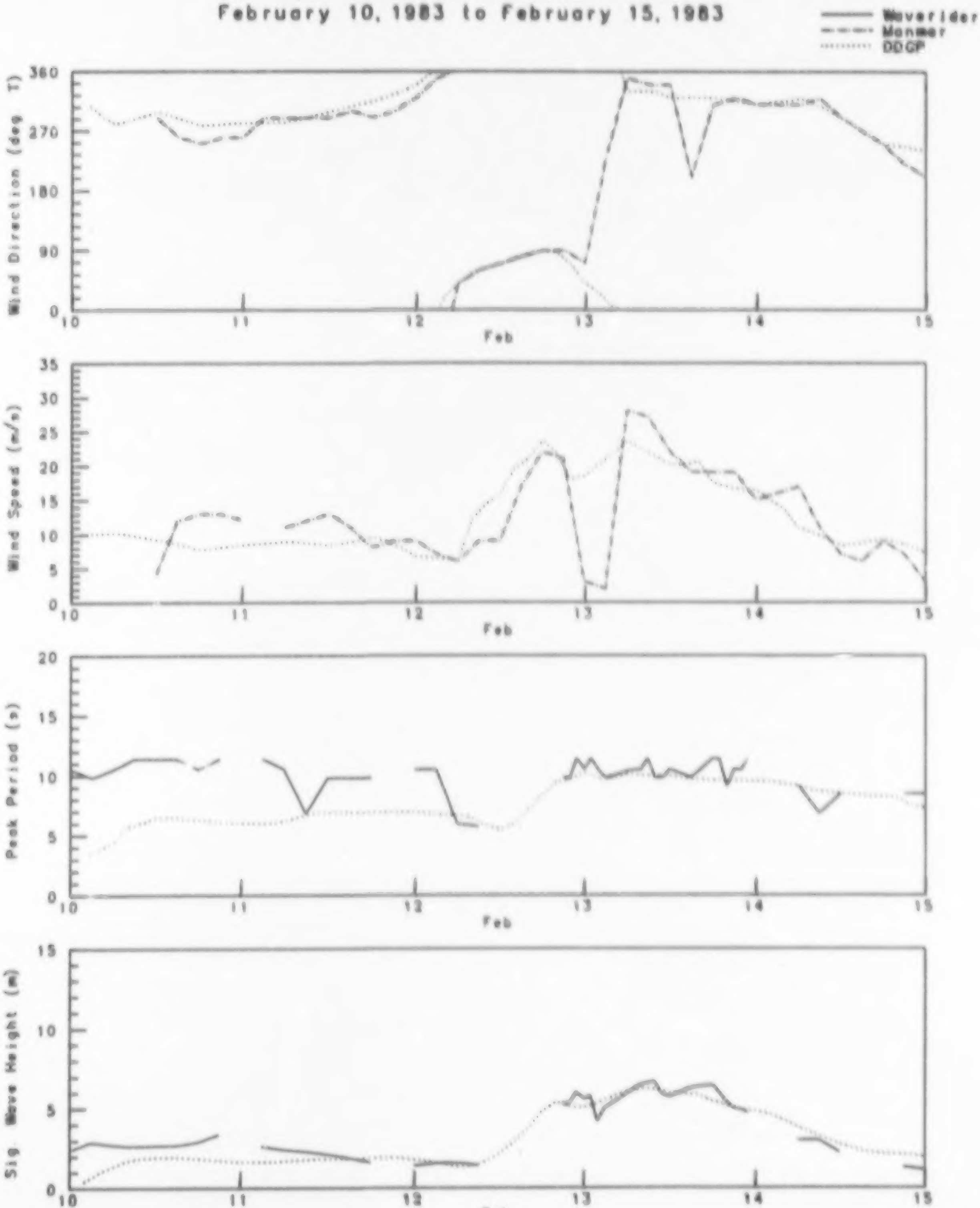


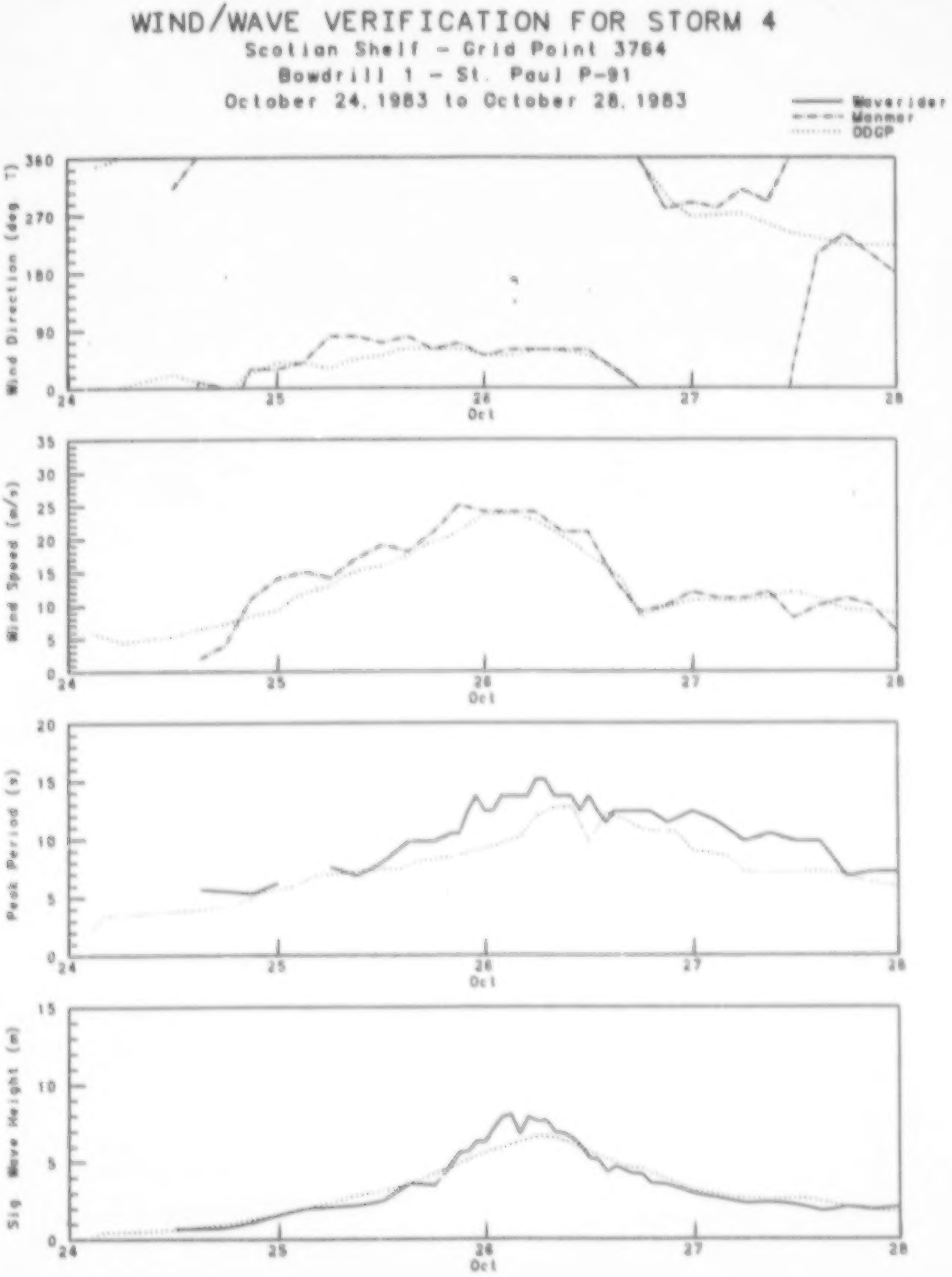
WIND/WAVE VERIFICATION FOR STORM 3

Scotian Shelf - Grid Point 3619

Zapata Scotian - Arcadia J-16

February 10, 1983 to February 15, 1983



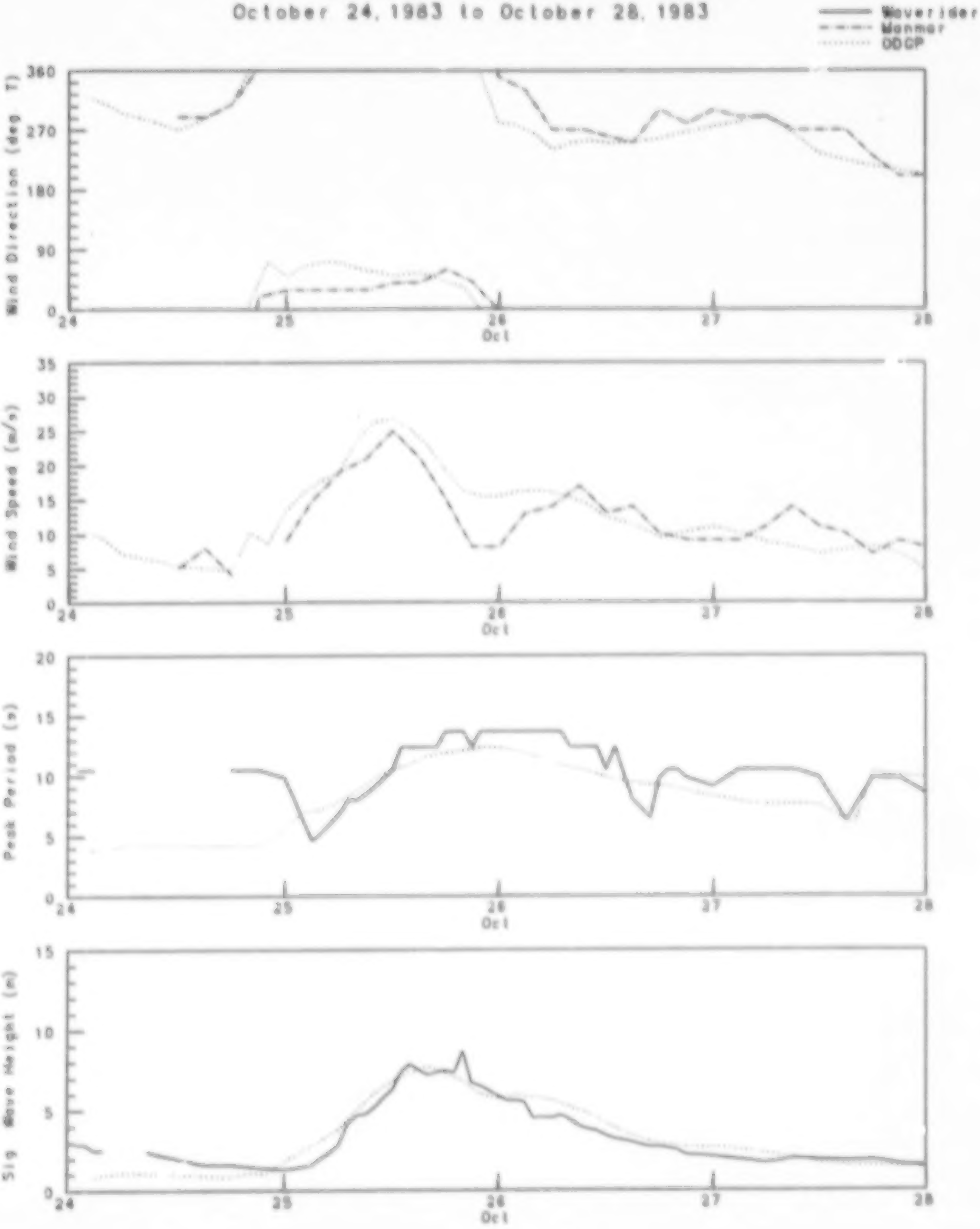


WIND/WAVE VERIFICATION FOR STORM 4

Scotian Shelf - Grid Point 3764
Bowdrill 1 - St. Paul P-91
October 24, 1983 to October 28, 1983

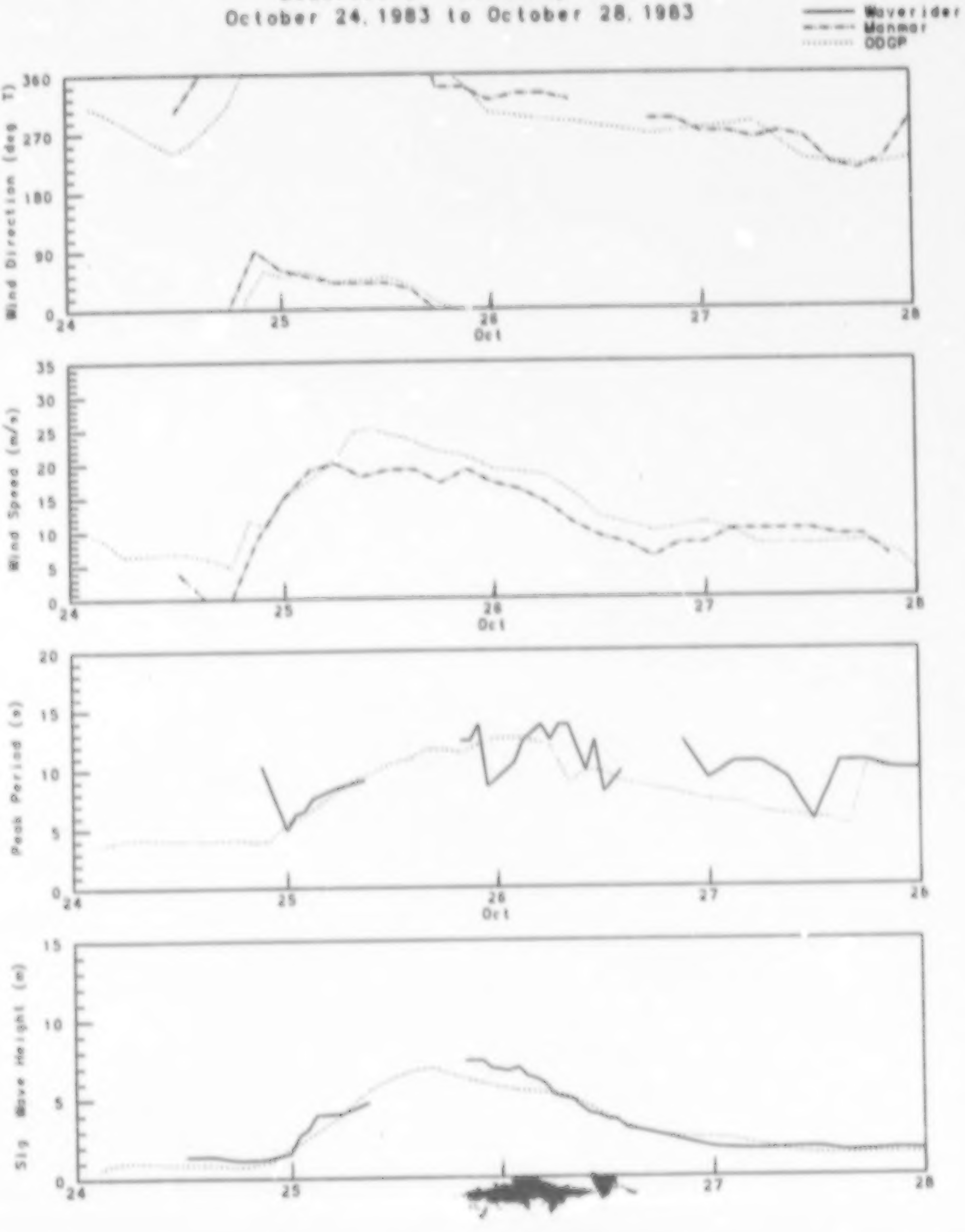
WIND/WAVE VERIFICATION FOR STORM 4

Scotian Shelf - Grid Point 3590
Vinland - Uniake G-72
October 24, 1983 to October 28, 1983



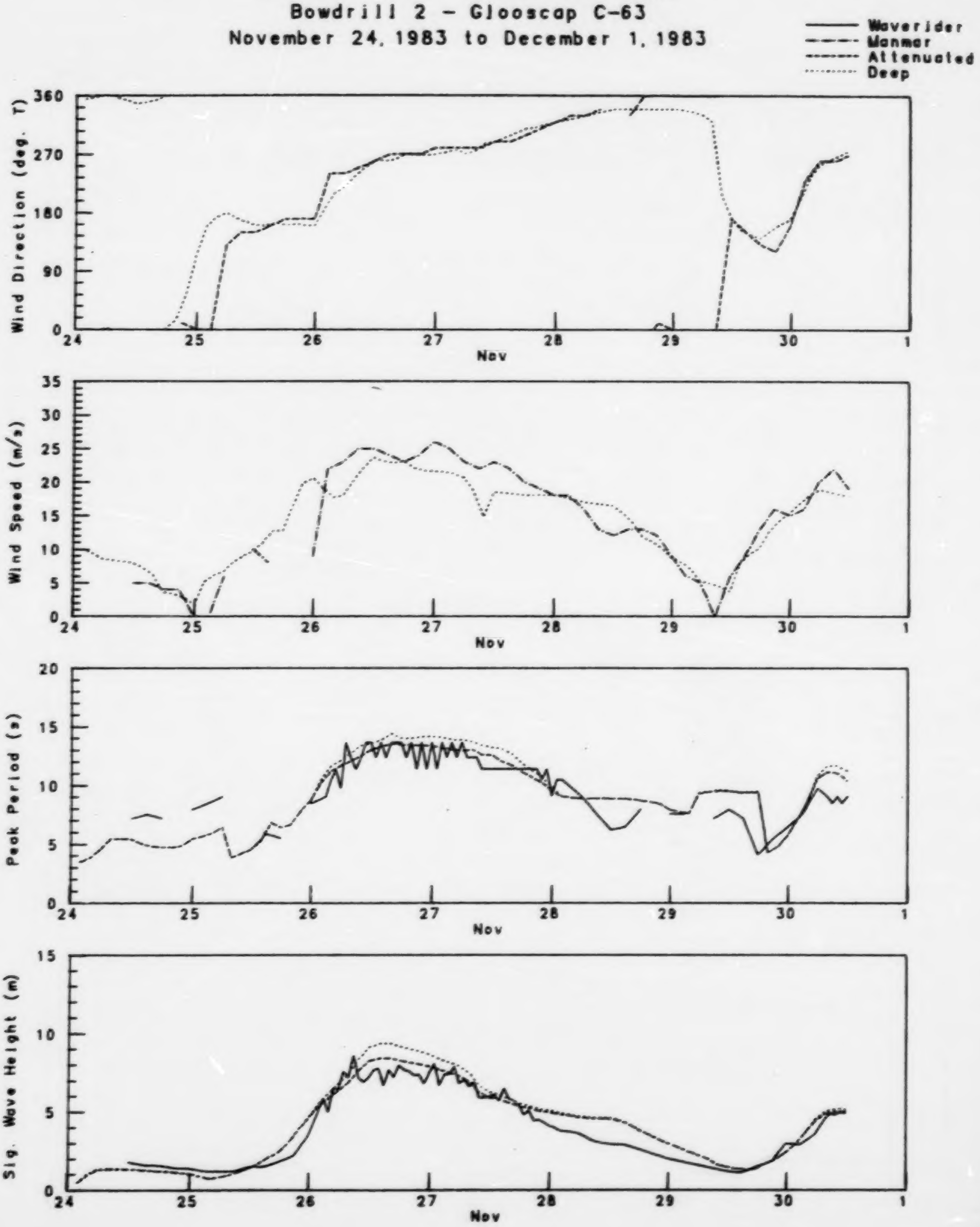
WIND/WAVE VERIFICATION FOR STORM 4

Scotian Shelf - Grid Point 3589
Bowdrill 2 - Glooscap C-63
October 24, 1983 to October 28, 1983



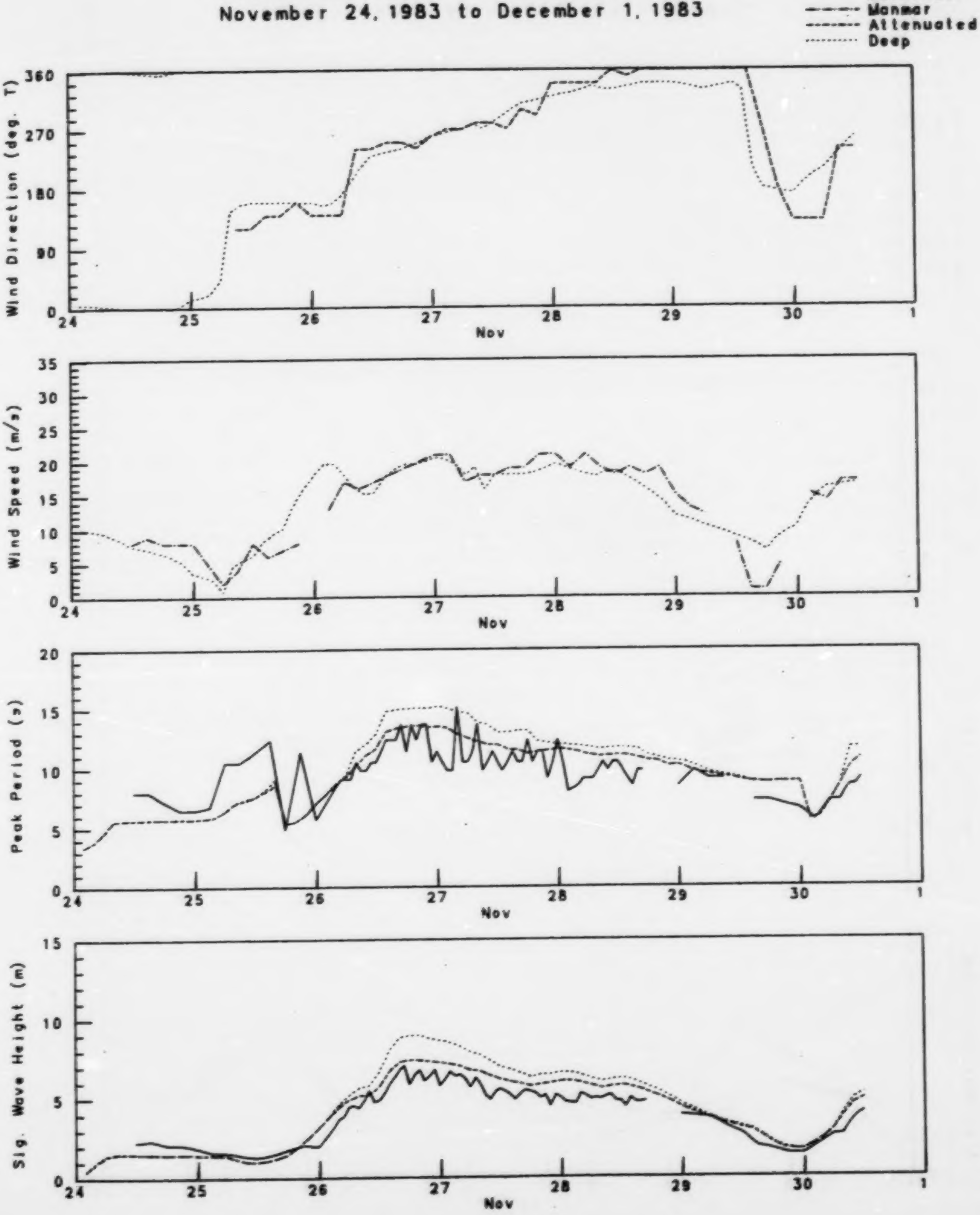
WIND/WAVE VERIFICATION FOR STORM 5

Scotian Shelf – Grid Point 3589
Bowdrill 2 – Glooscap C-63
November 24, 1983 to December 1, 1983



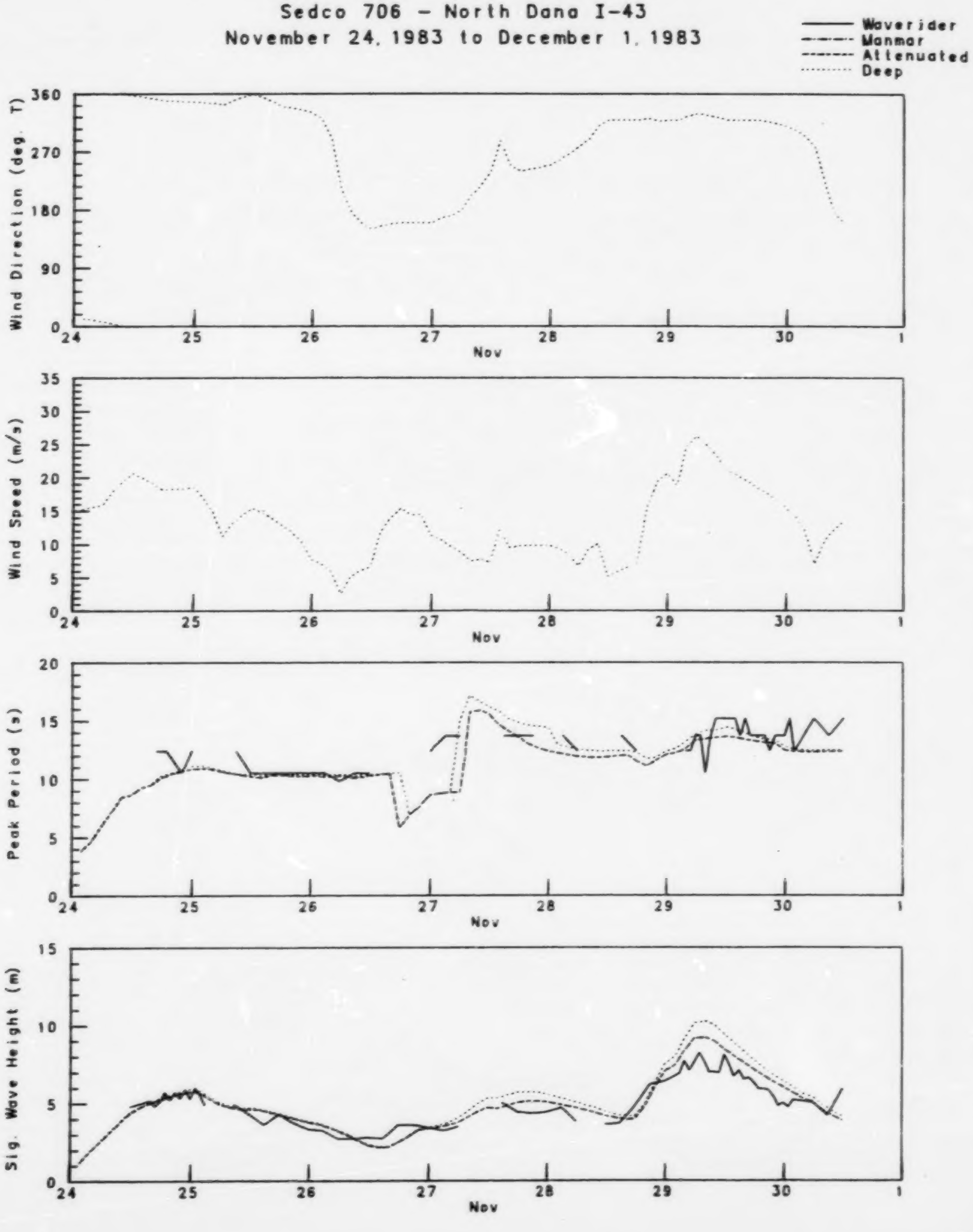
WIND/WAVE VERIFICATION FOR STORM 5

Scotian Shelf – Grid Point 3620
Glomar Labrador 1 – Louisbourg J-47
November 24, 1983 to December 1, 1983



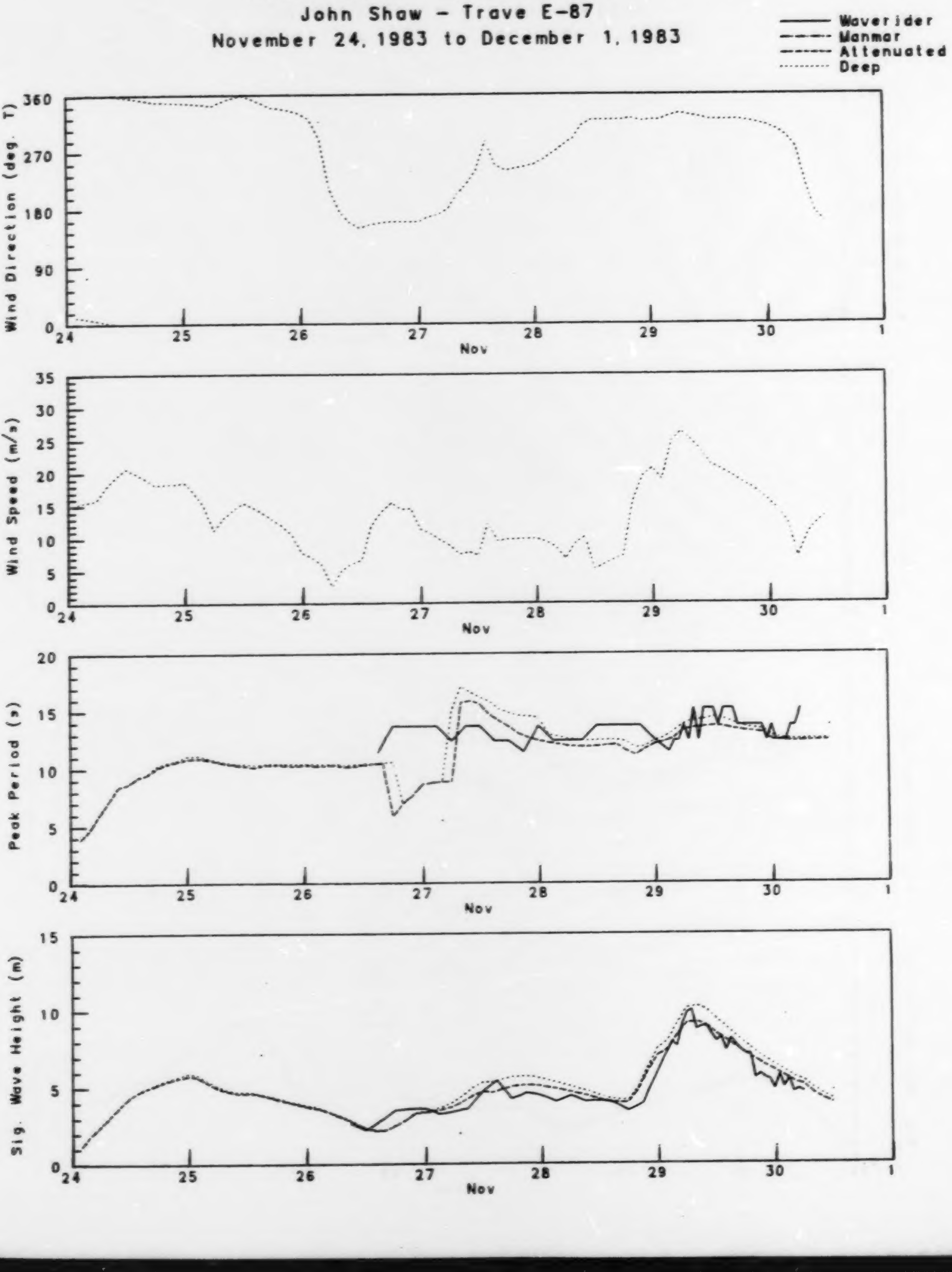
WIND/WAVE VERIFICATION FOR STORM 5

Grand Banks – Grid Point 3745
Sedco 706 – North Dana I-43
November 24, 1983 to December 1, 1983



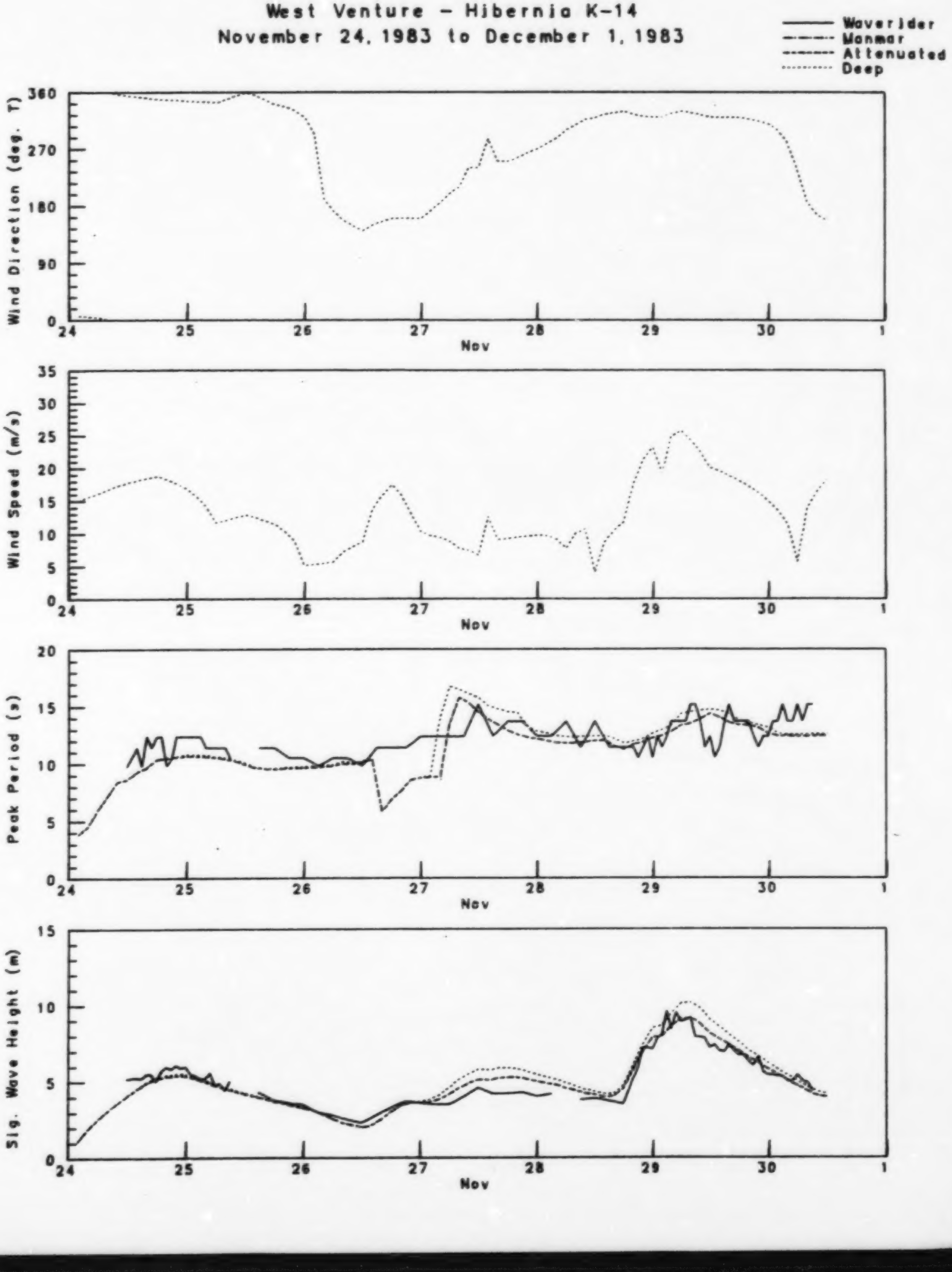
WIND/WAVE VERIFICATION FOR STORM 5

Grand Banks - Grid Point 3745
John Shaw - Trave E-87
November 24, 1983 to December 1, 1983



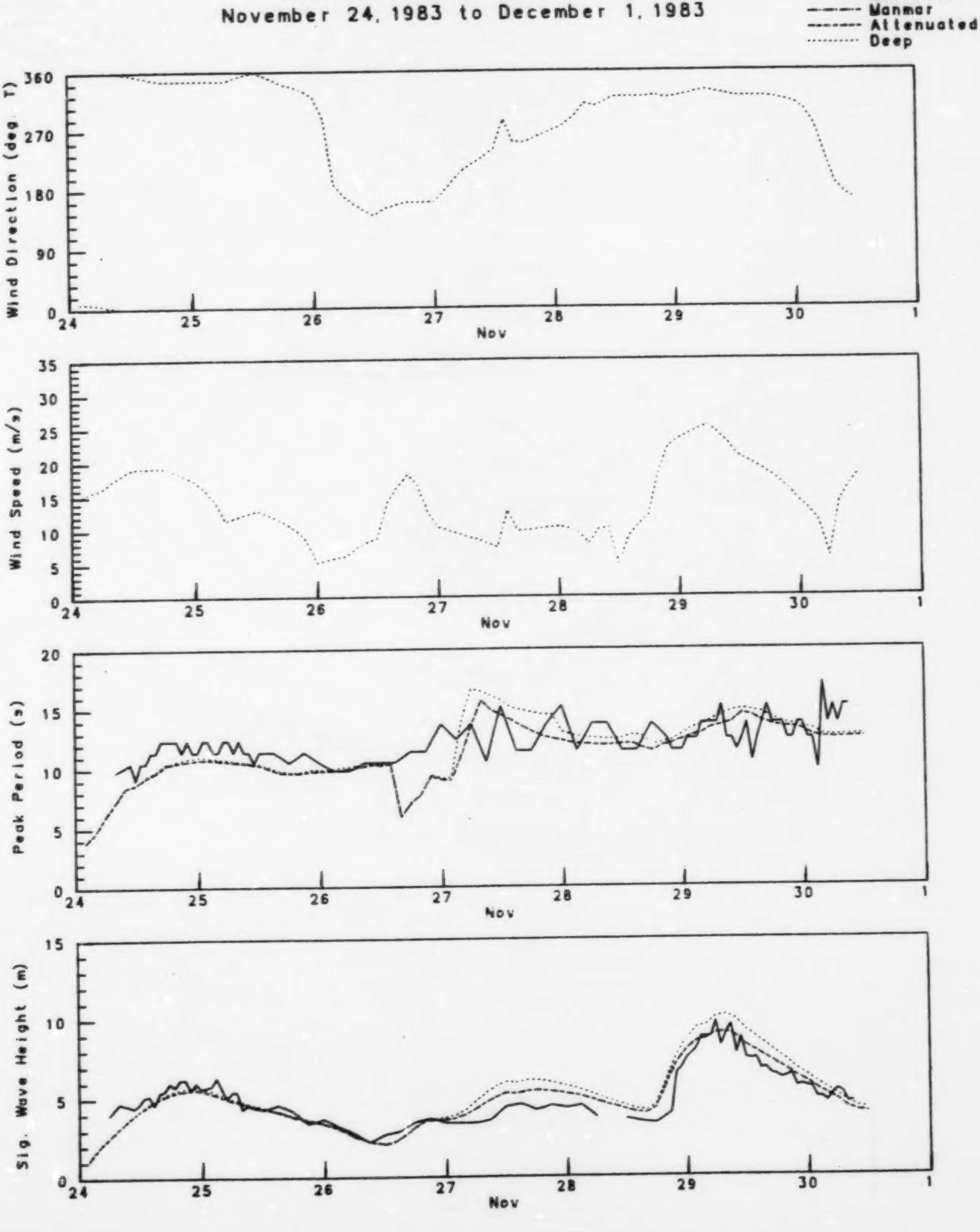
WIND/WAVE VERIFICATION FOR STORM 5

Grand Banks - Grid Point 3744
West Venture - Hibernia K-14
November 24, 1983 to December 1, 1983



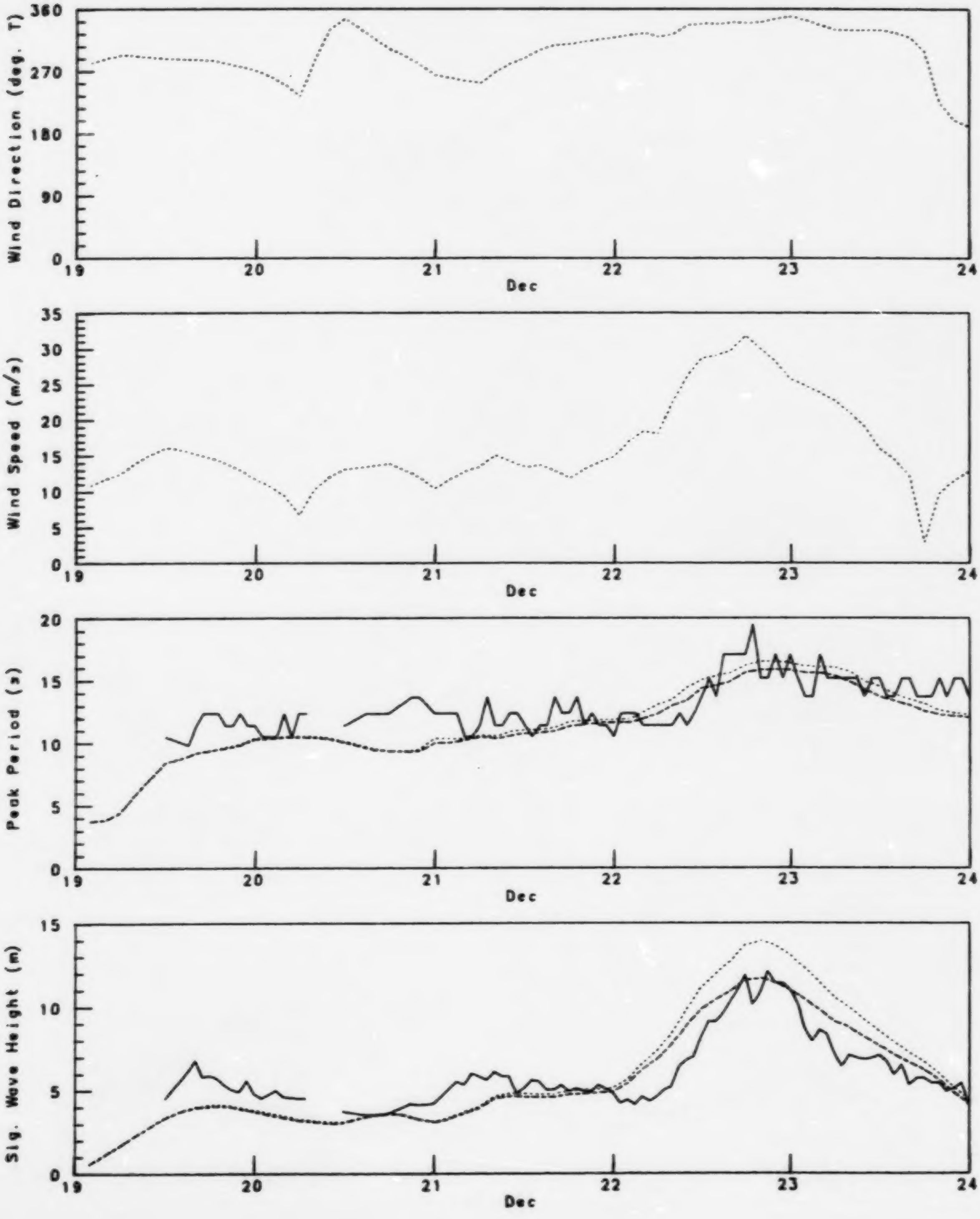
WIND/WAVE VERIFICATION FOR STORM 5

Grand Banks – Grid Point 3715
Sedco 710 – Terra Nova K-08
November 24, 1983 to December 1, 1983



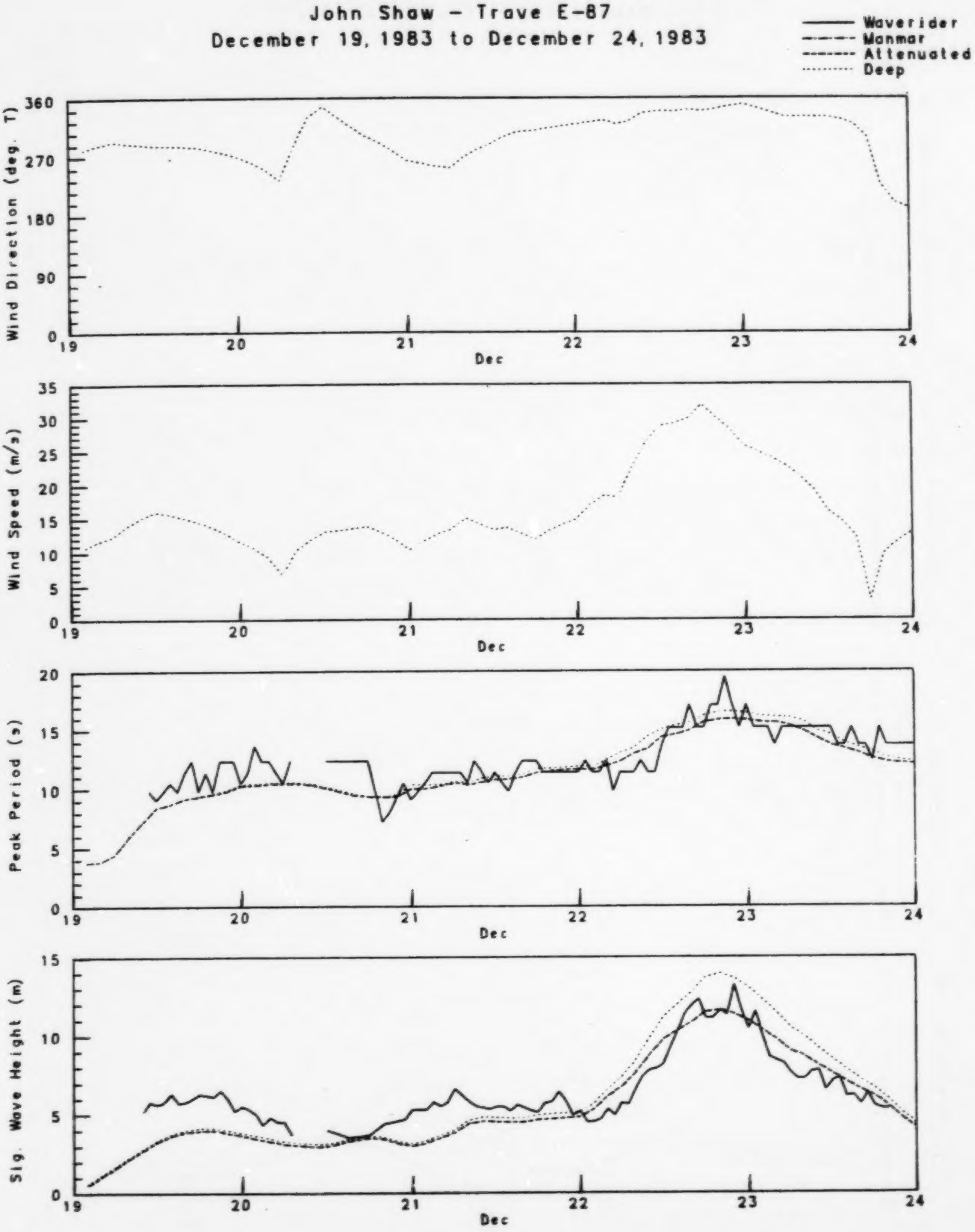
WIND/WAVE VERIFICATION FOR STORM 6

Grand Banks - Grid Point 3745
Sedco 706 - North Dana I-43
December 19, 1983 to December 24, 1983



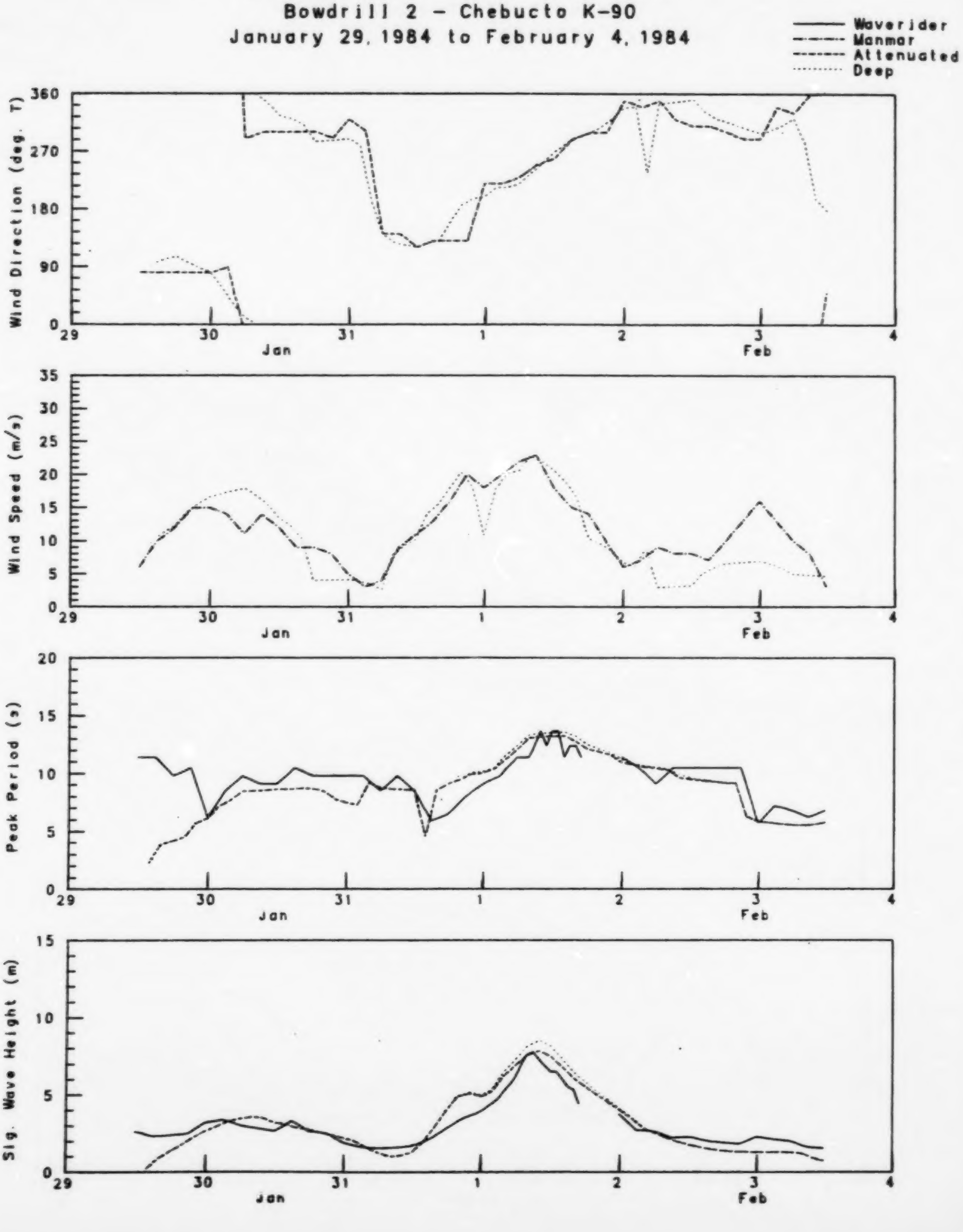
WIND/WAVE VERIFICATION FOR STORM 6

Grand Banks - Grid Point 3745
John Shaw - Trave E-87
December 19, 1983 to December 24, 1983



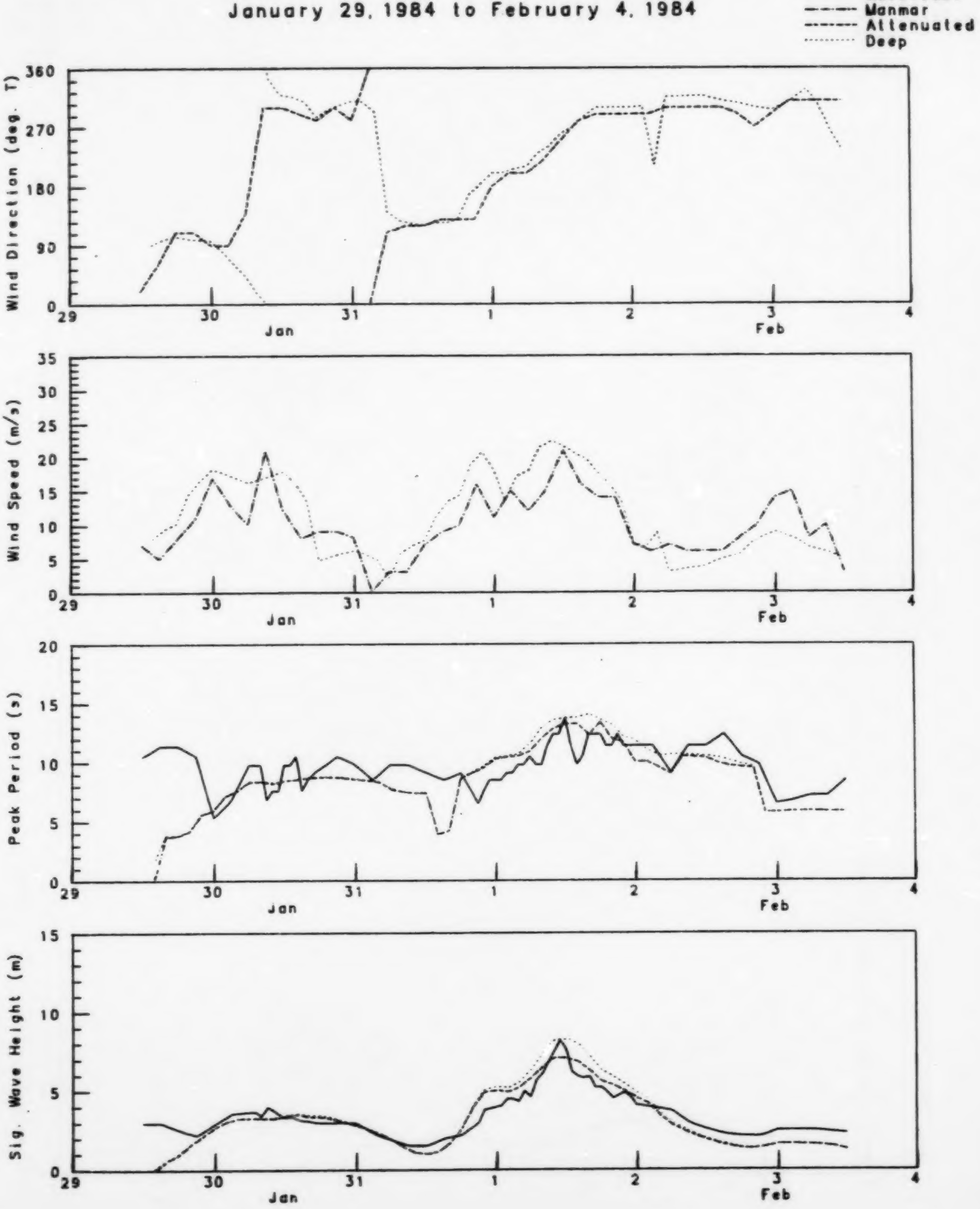
WIND/WAVE VERIFICATION FOR STORM 7

Scotian Shelf - Grid Point 3590
Bowdrill 2 - Chebucto K-90
January 29, 1984 to February 4, 1984



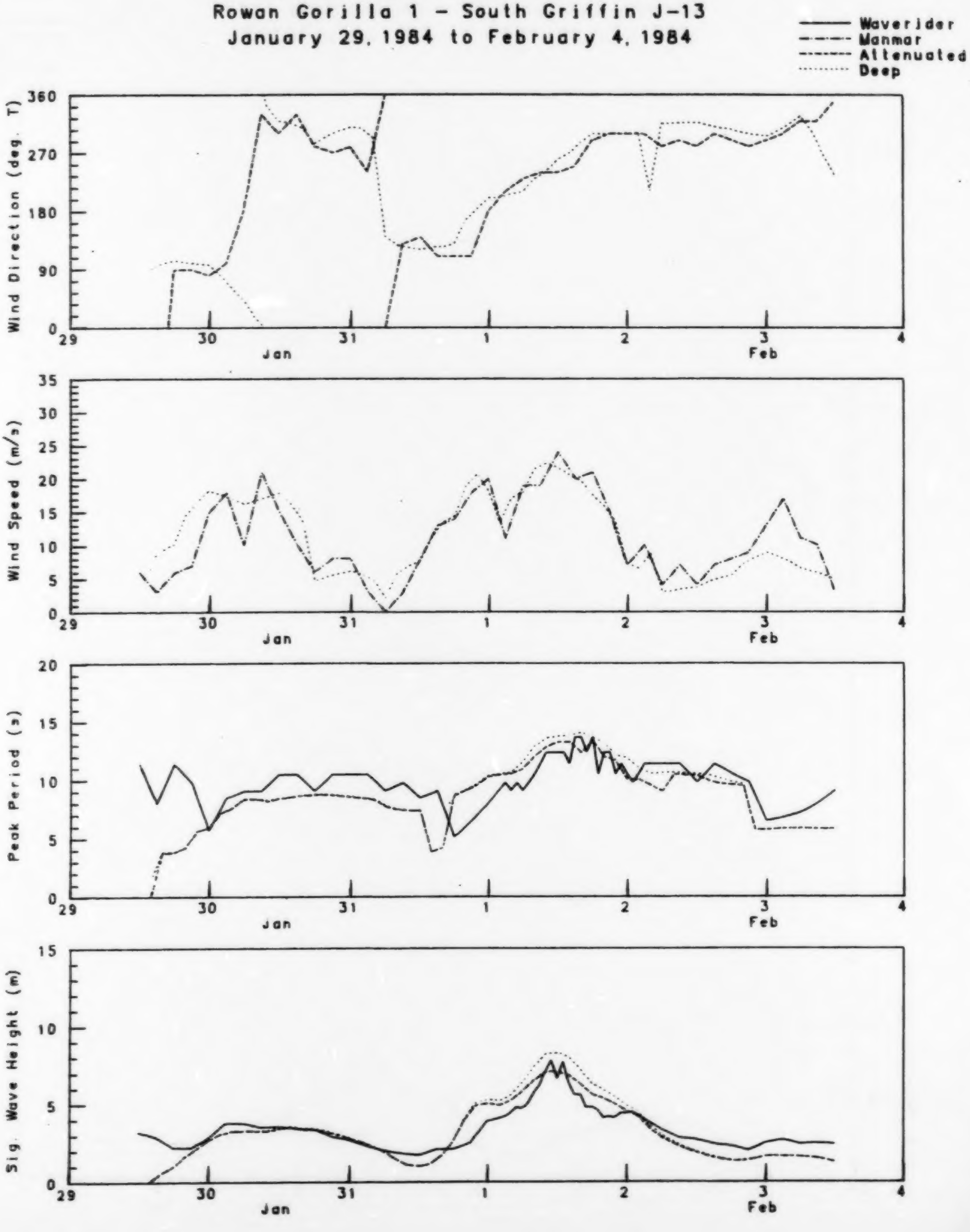
WIND/WAVE VERIFICATION FOR STORM 7

Scotian Shelf – Grid Point 3620
Glomar Labrador 1 – Louisbourg J-47
January 29, 1984 to February 4, 1984



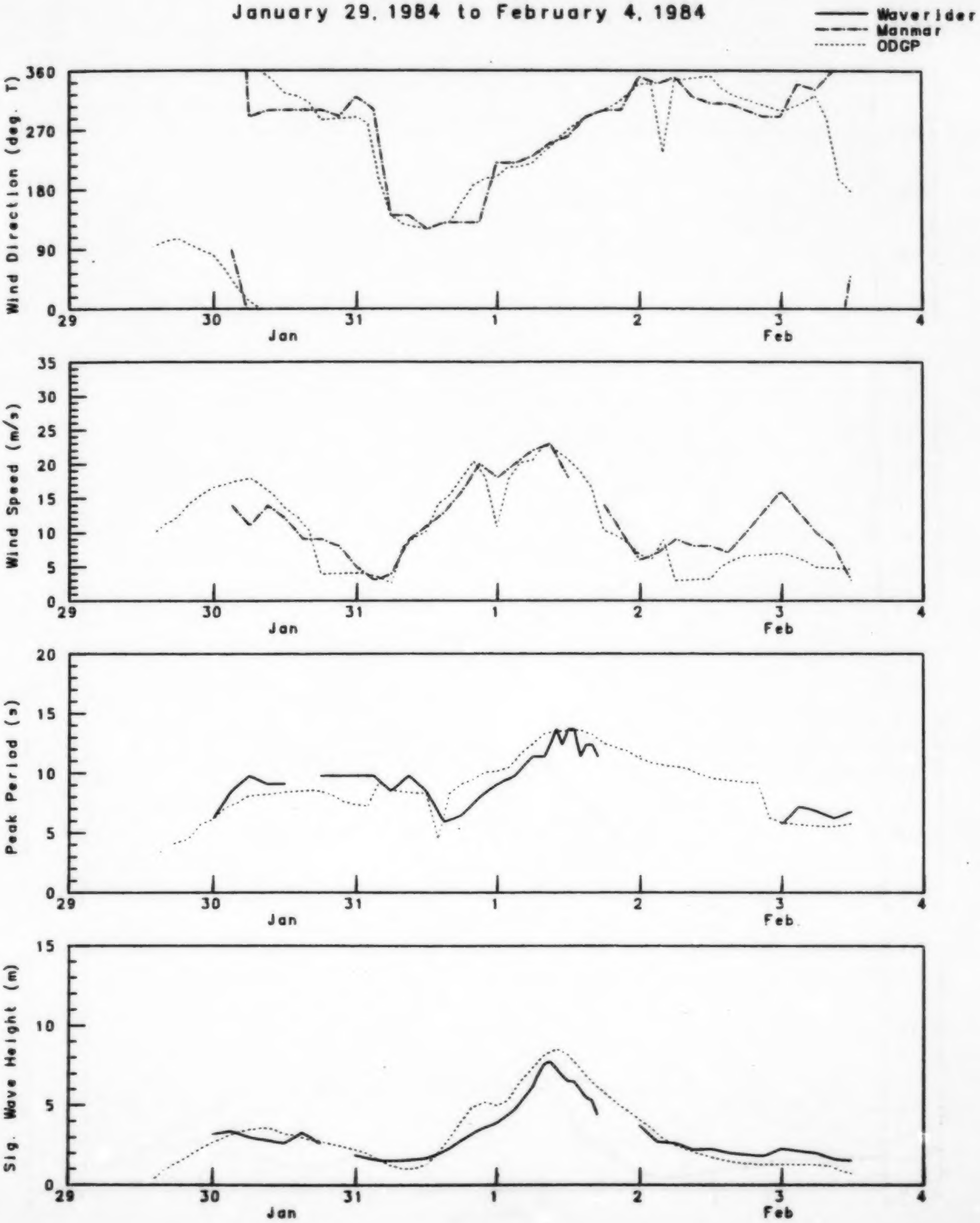
WIND/WAVE VERIFICATION FOR STORM 7

Scotian Shelf - Grid Point 3620
Rowan Gorilla 1 - South Griffin J-13
January 29, 1984 to February 4, 1984



WIND/WAVE VERIFICATION FOR STORM 7

Scotian Shelf - Grid Point 3590
Bowdrill 2 - Chebucto K-90
January 29, 1984 to February 4, 1984

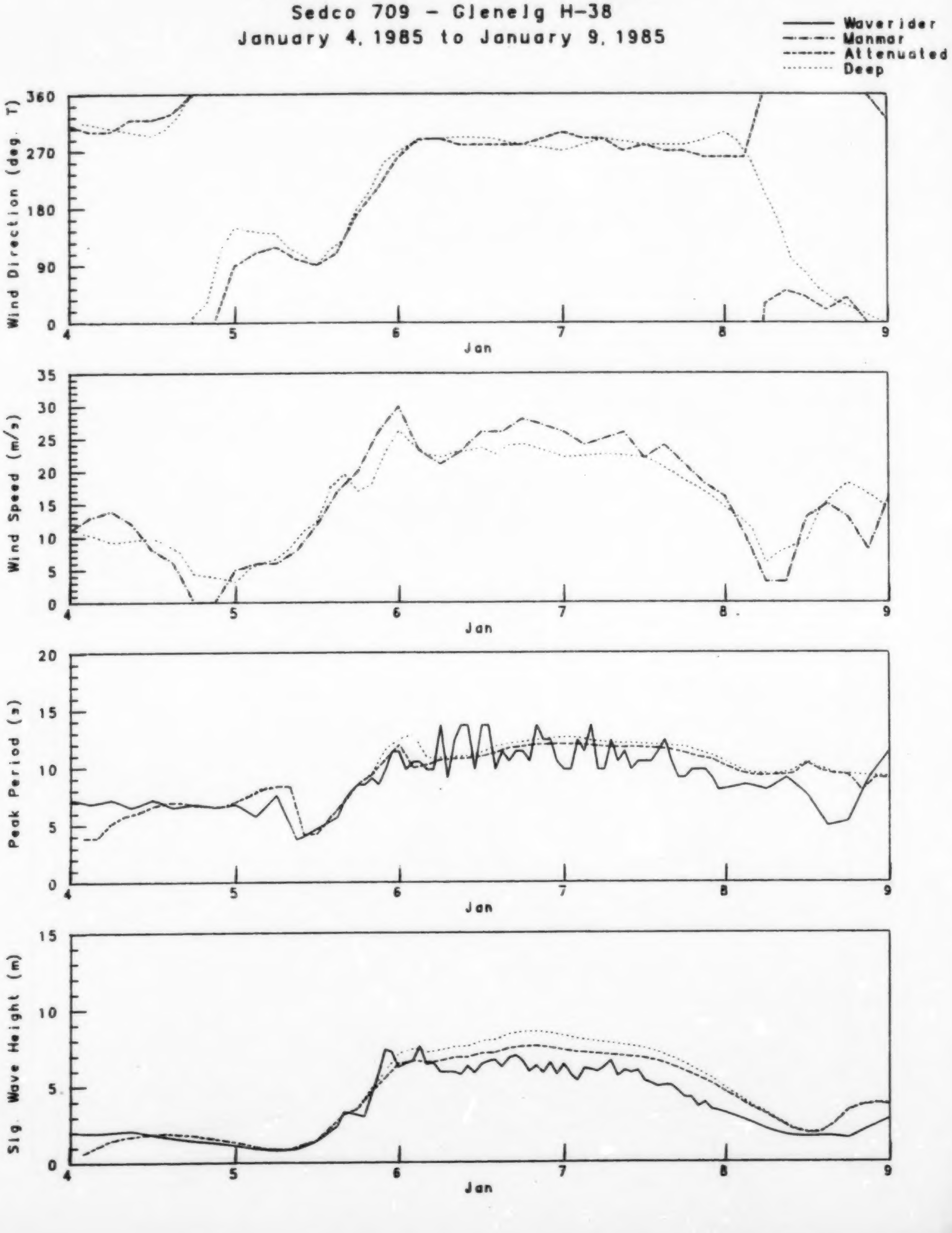


WIND/WAVE VERIFICATION FOR STORM 8

Scotian Shelf - Grid Point 3590

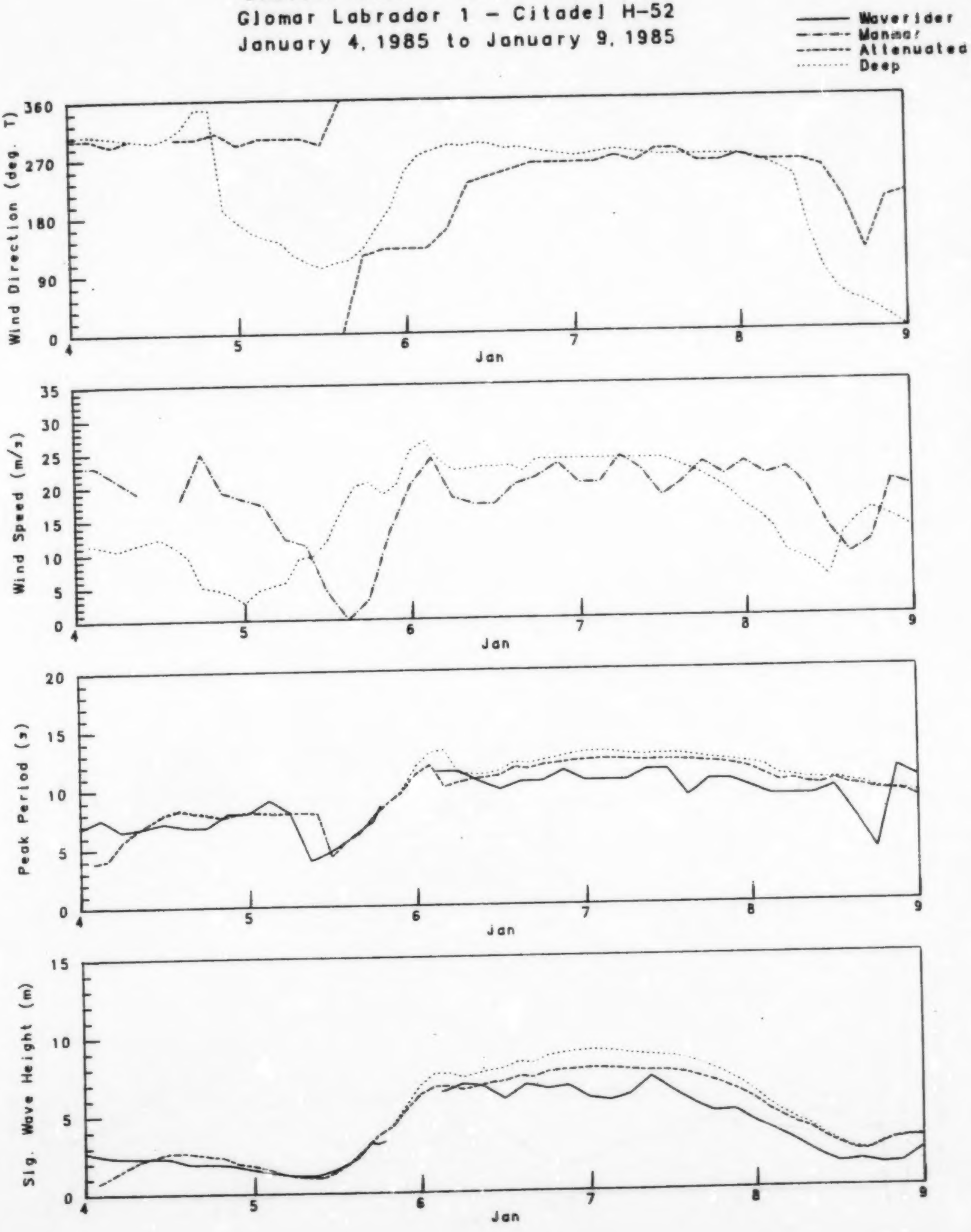
Sedco 709 - Glenelg H-38

January 4, 1985 to January 9, 1985



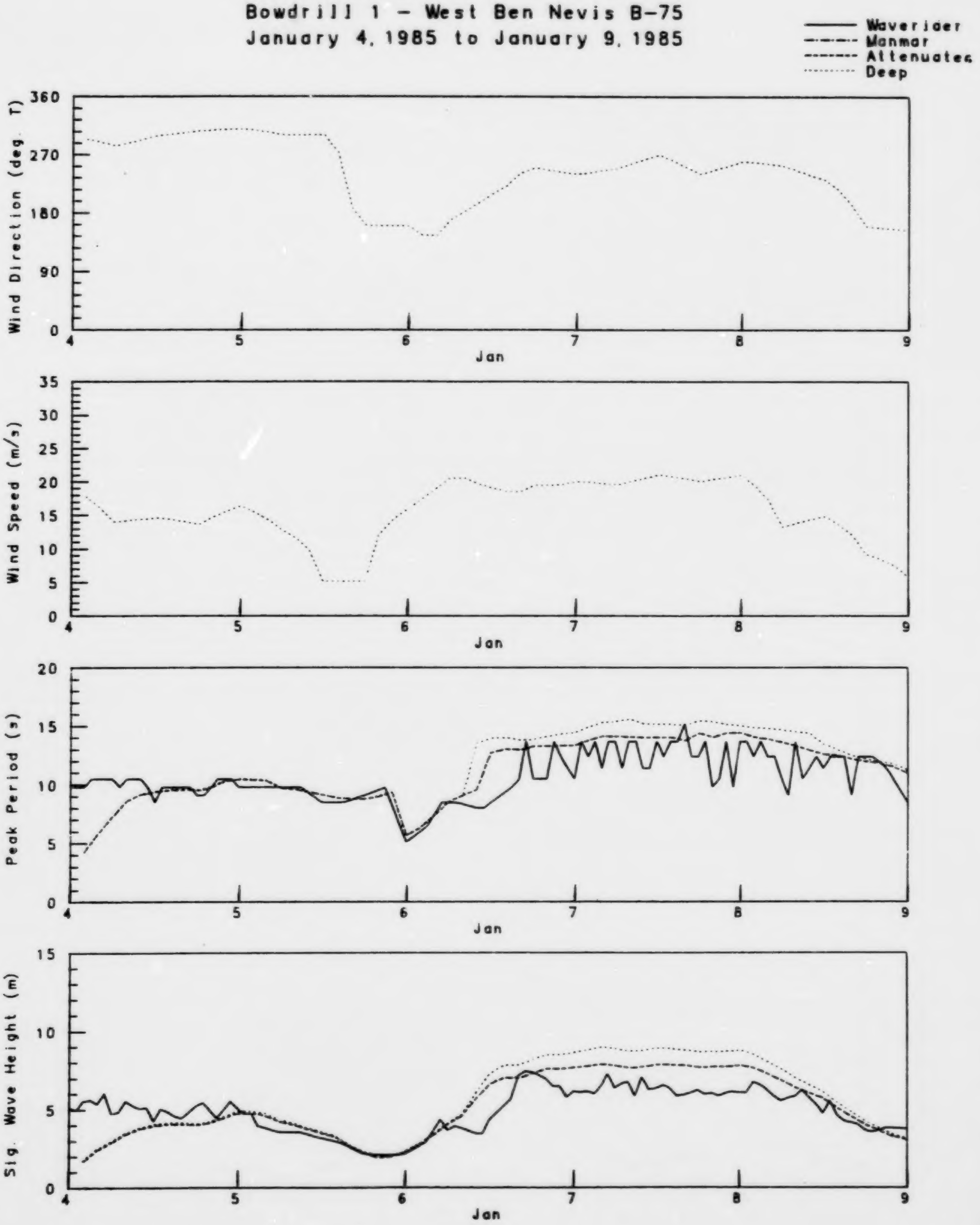
WIND/WAVE VERIFICATION FOR STORM 8

Scotian Shelf - Grid Point 3620
Glomar Labrador 1 - Citadel H-52
January 4, 1985 to January 9, 1985



WIND/WAVE VERIFICATION FOR STORM 8

Grand Banks - Grid Point 3744
Bowdrill 1 - West Ben Nevis B-75
January 4, 1985 to January 9, 1985

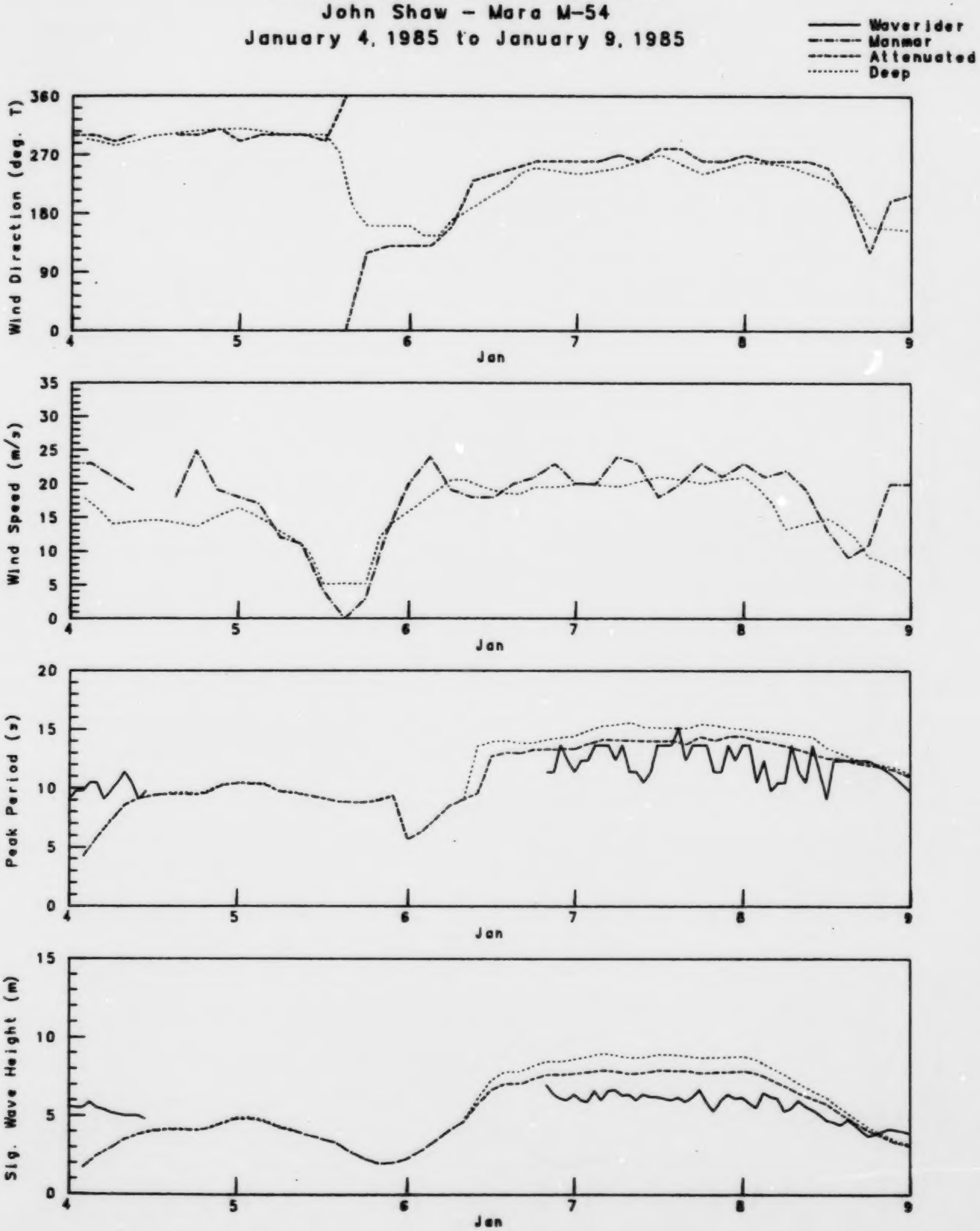


WIND/WAVE VERIFICATION FOR STORM 8

Grand Banks - Grid Point 3744

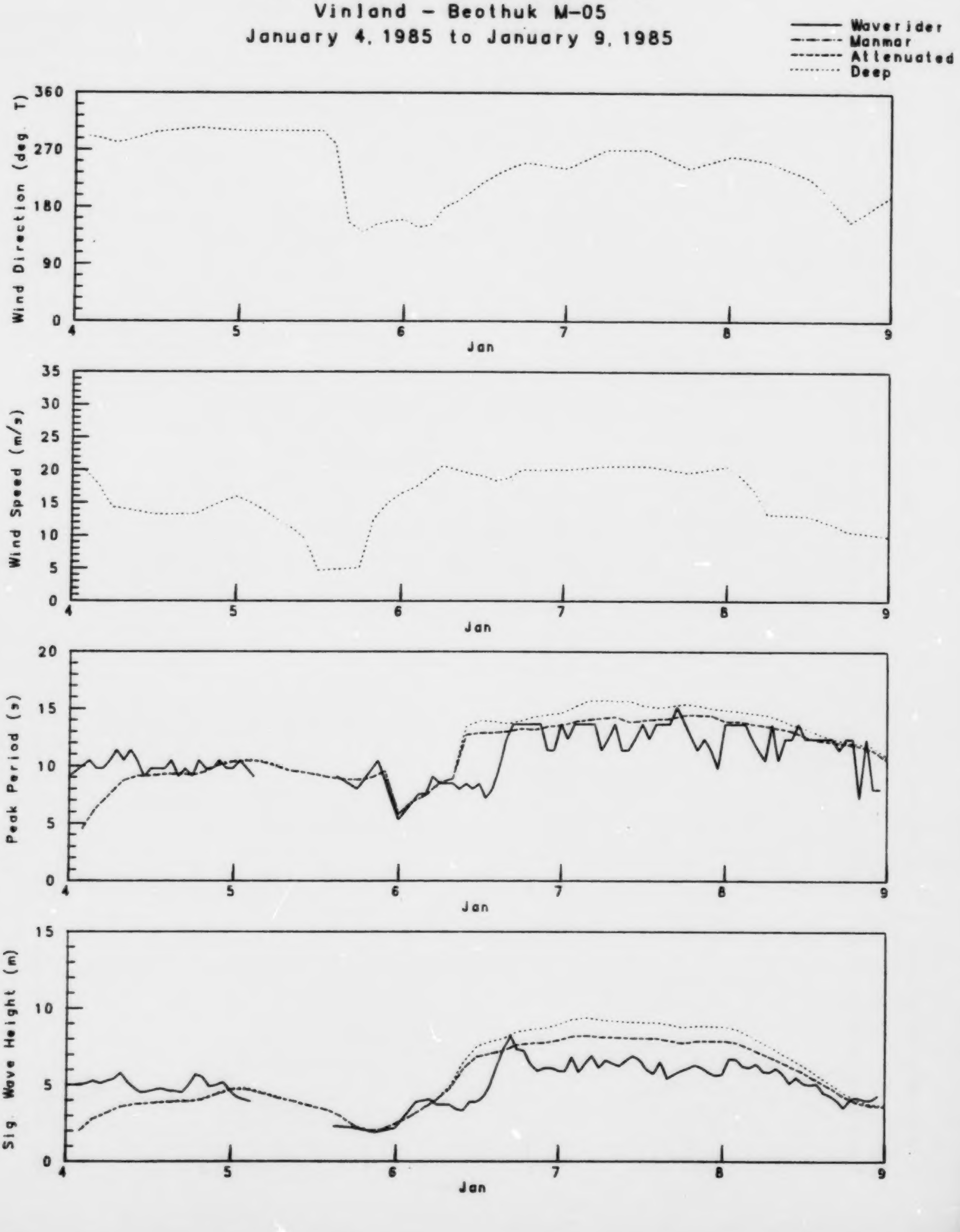
John Shaw - Mara M-54

January 4, 1985 to January 9, 1985



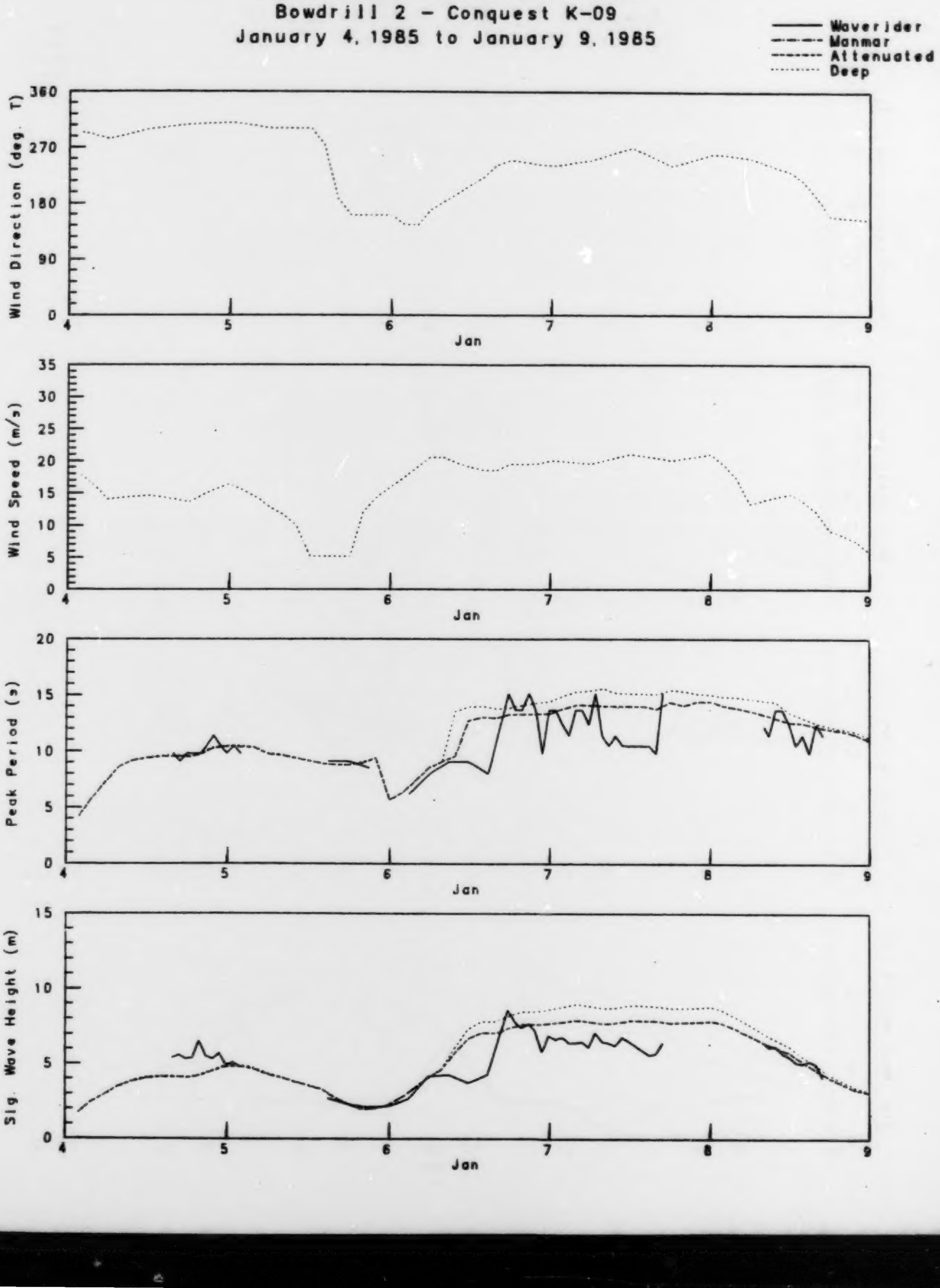
WIND/WAVE VERIFICATION FOR STORM 8

Grand Banks - Grid Point 3715
Vinland - Beothuk M-05
January 4, 1985 to January 9, 1985



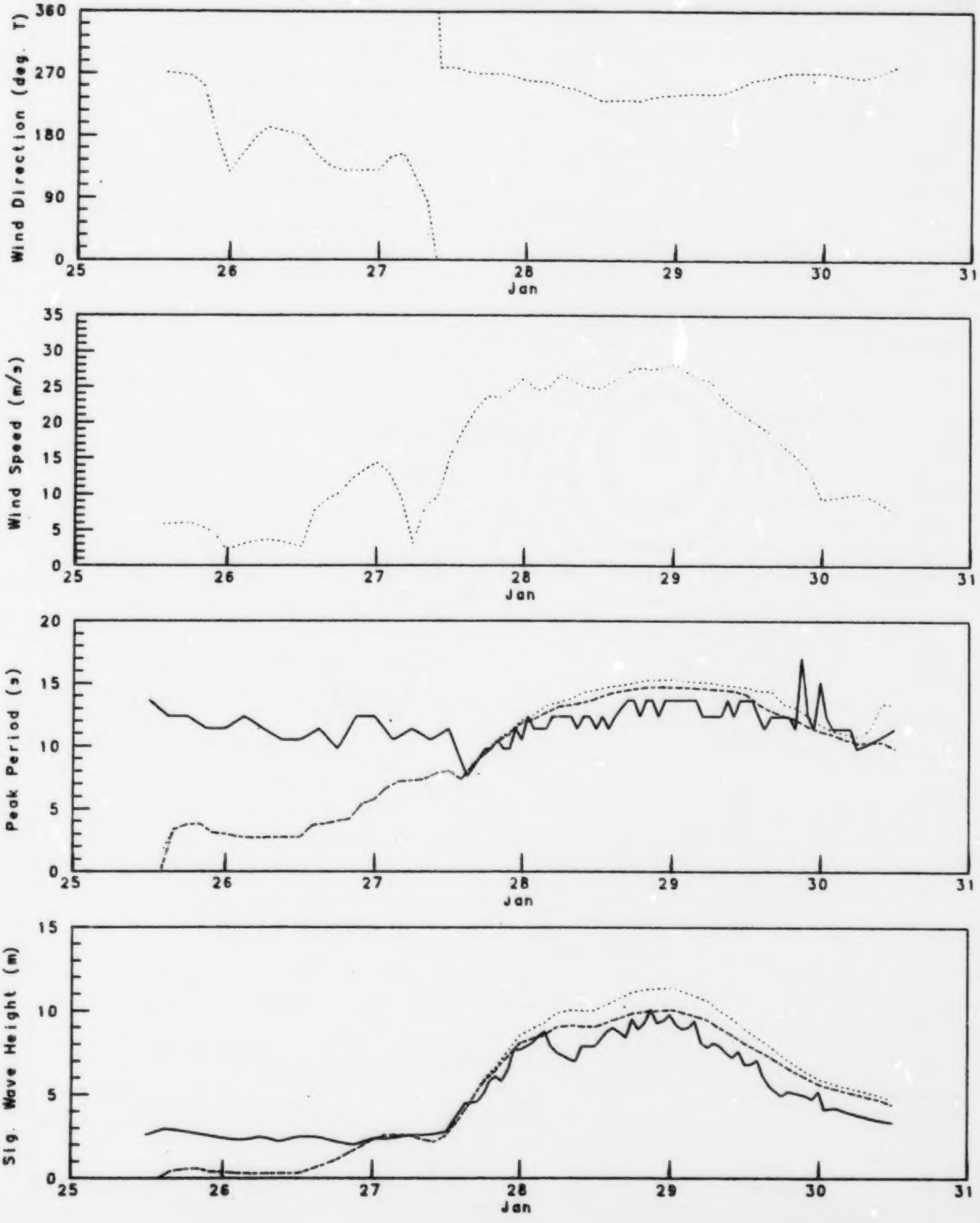
WIND/WAVE VERIFICATION FOR STORM 8

Grand Banks - Grid Point 3744
Bowdrill 2 - Conquest K-09
January 4, 1985 to January 9, 1985



WIND/WAVE VERIFICATION FOR STORM 9

Grand Banks - Grid Point 3744
Bowdrill 1 - West Ben Nevis B-75
January 25, 1985 to January 31, 1985

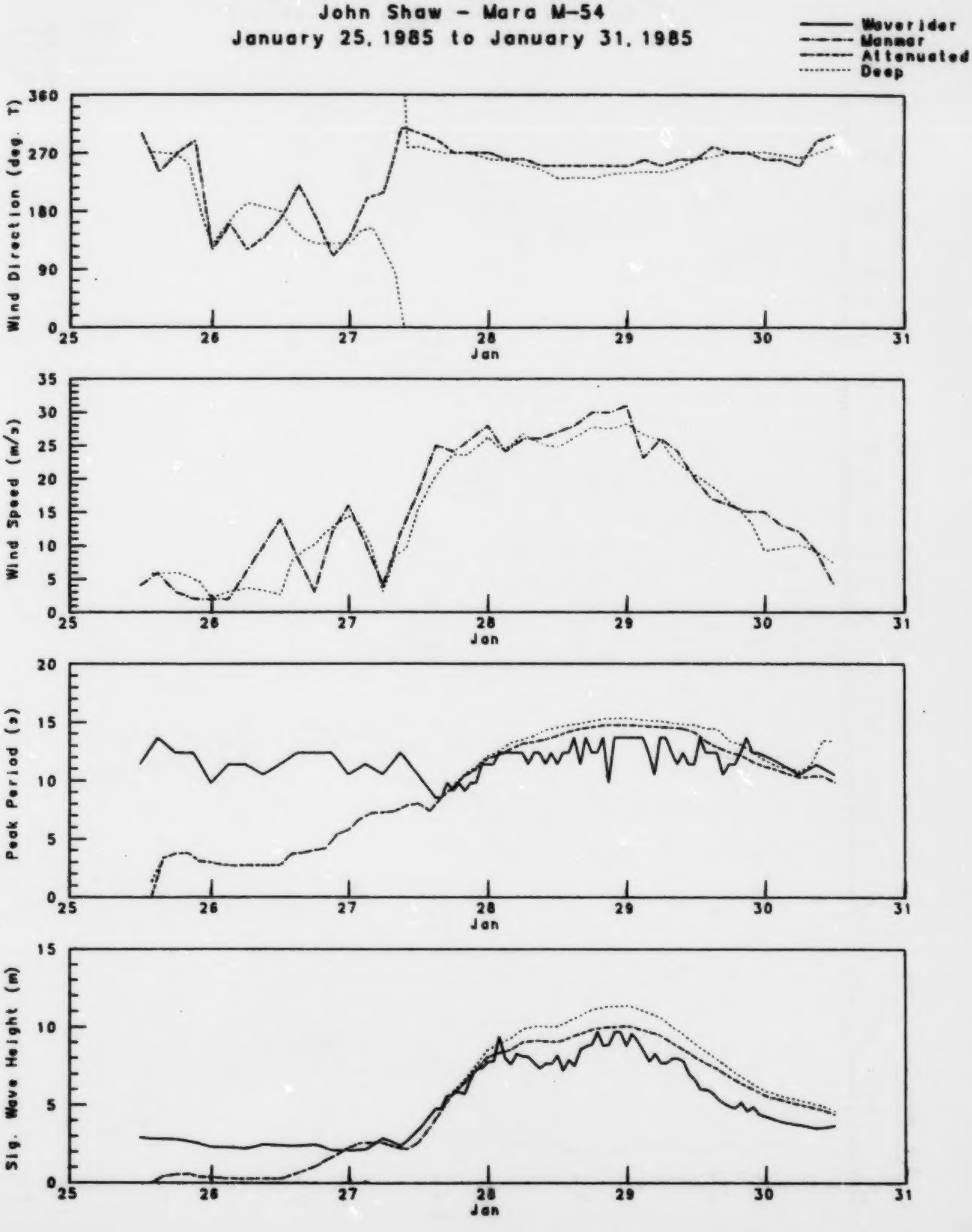


WIND/WAVE VERIFICATION FOR STORM 9

Grand Banks - Grid Point 3744

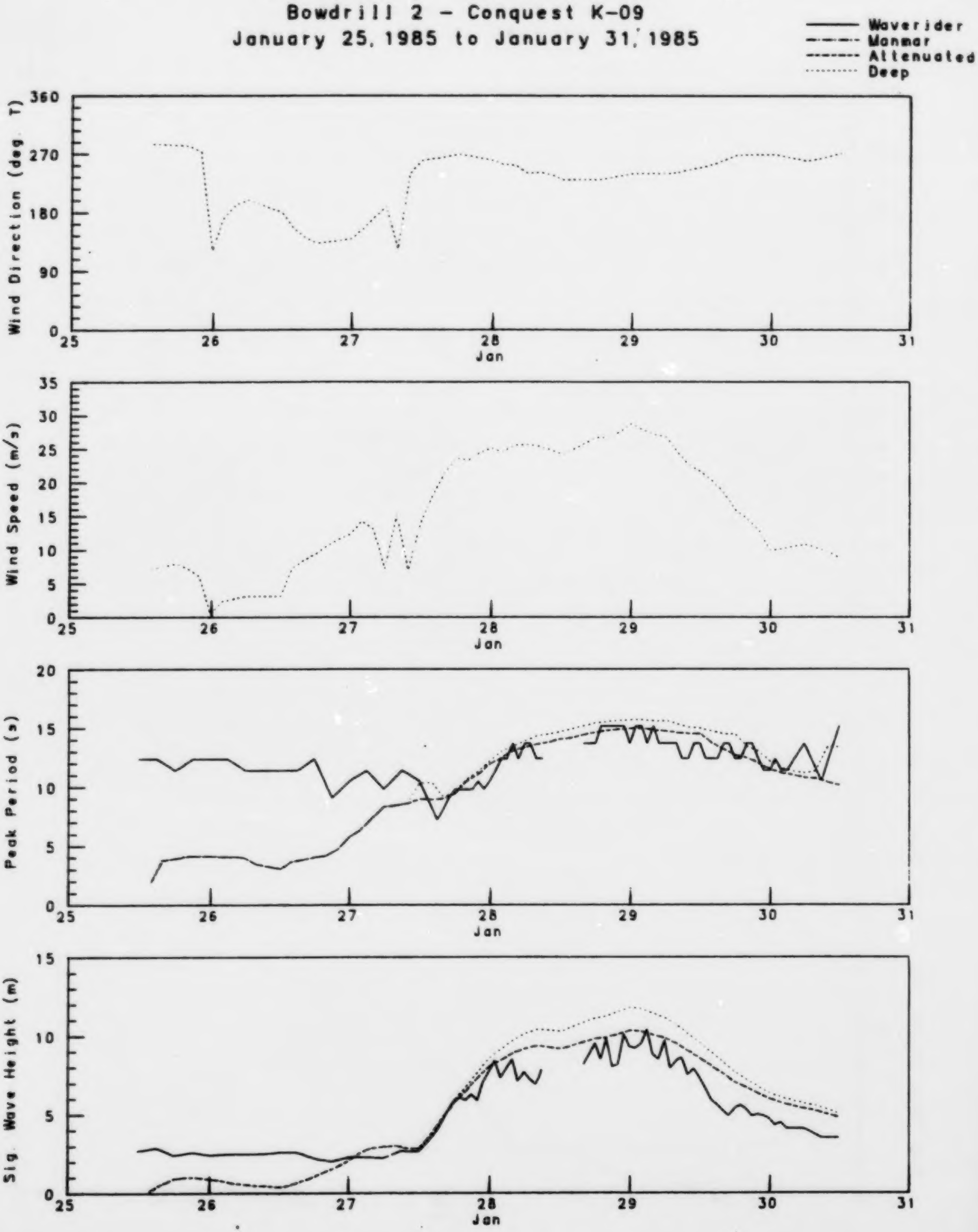
John Shaw - Mara M-54

January 25, 1985 to January 31, 1985



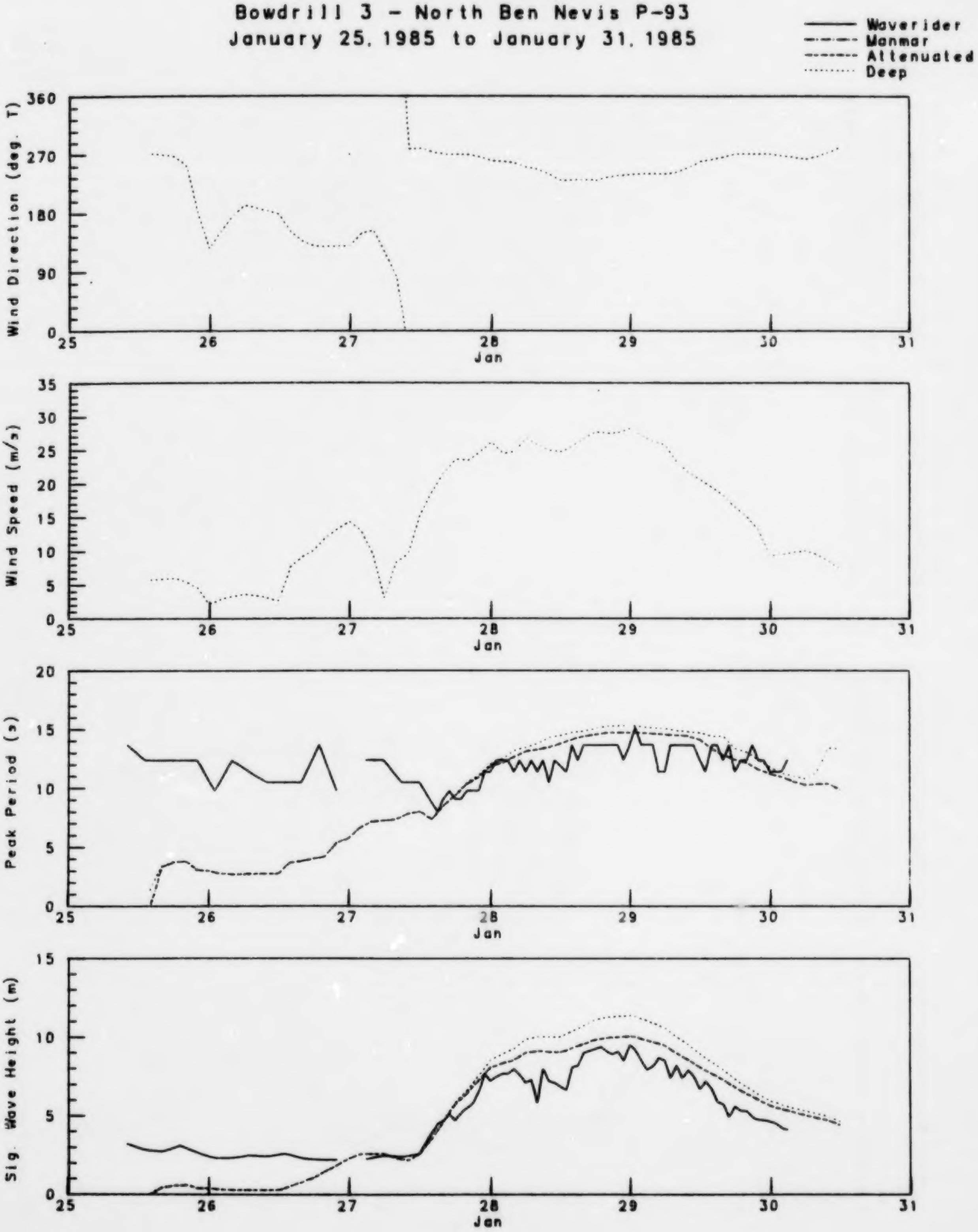
WIND/WAVE VERIFICATION FOR STORM 9

Grand Banks - Grid Point 3745
Bowdrill 2 - Conquest K-09
January 25, 1985 to January 31, 1985



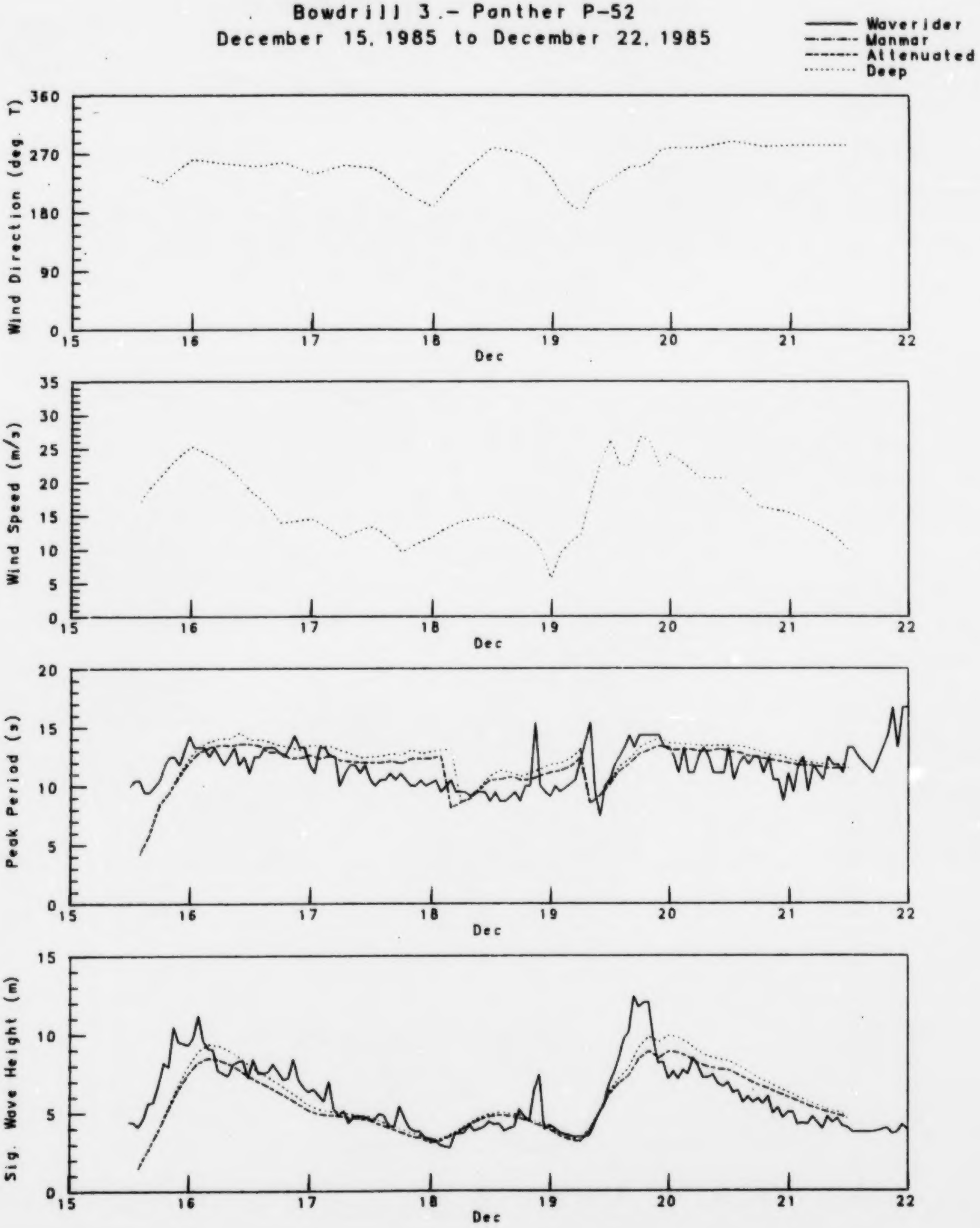
WIND/WAVE VERIFICATION FOR STORM 9

Grand Banks - Grid Point 3744
Bowdrill 3 - North Ben Nevis P-93
January 25, 1985 to January 31, 1985



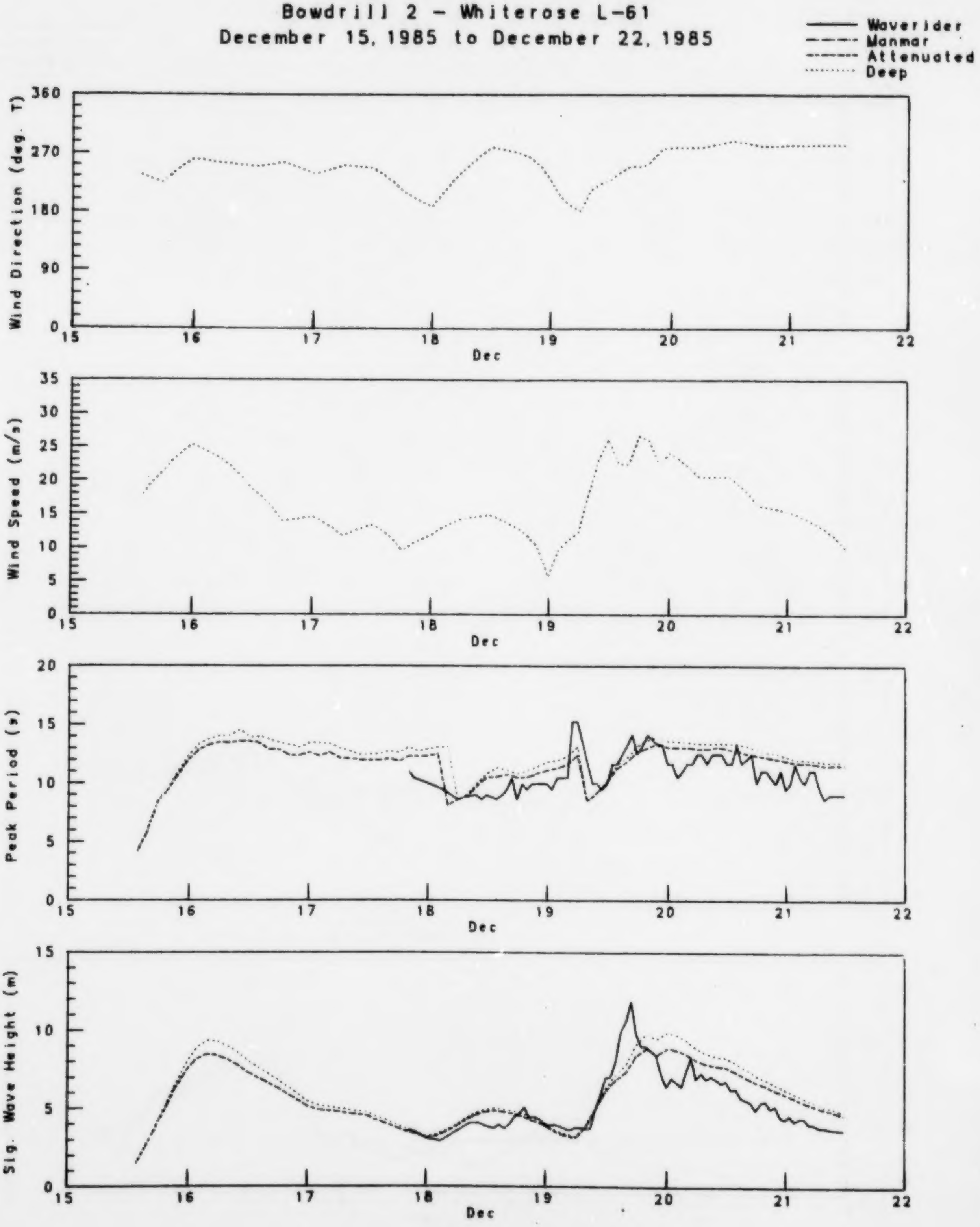
WIND/WAVE VERIFICATION FOR STORM 10

Grand Banks – Grid Point 3744
Bowdrill 3.– Panther P-52
December 15, 1985 to December 22, 1985



WIND/WAVE VERIFICATION FOR STORM 10

Grand Banks - Grid Point 3744
Bowdrill 2 - Whiterose L-61
December 15, 1985 to December 22, 1985

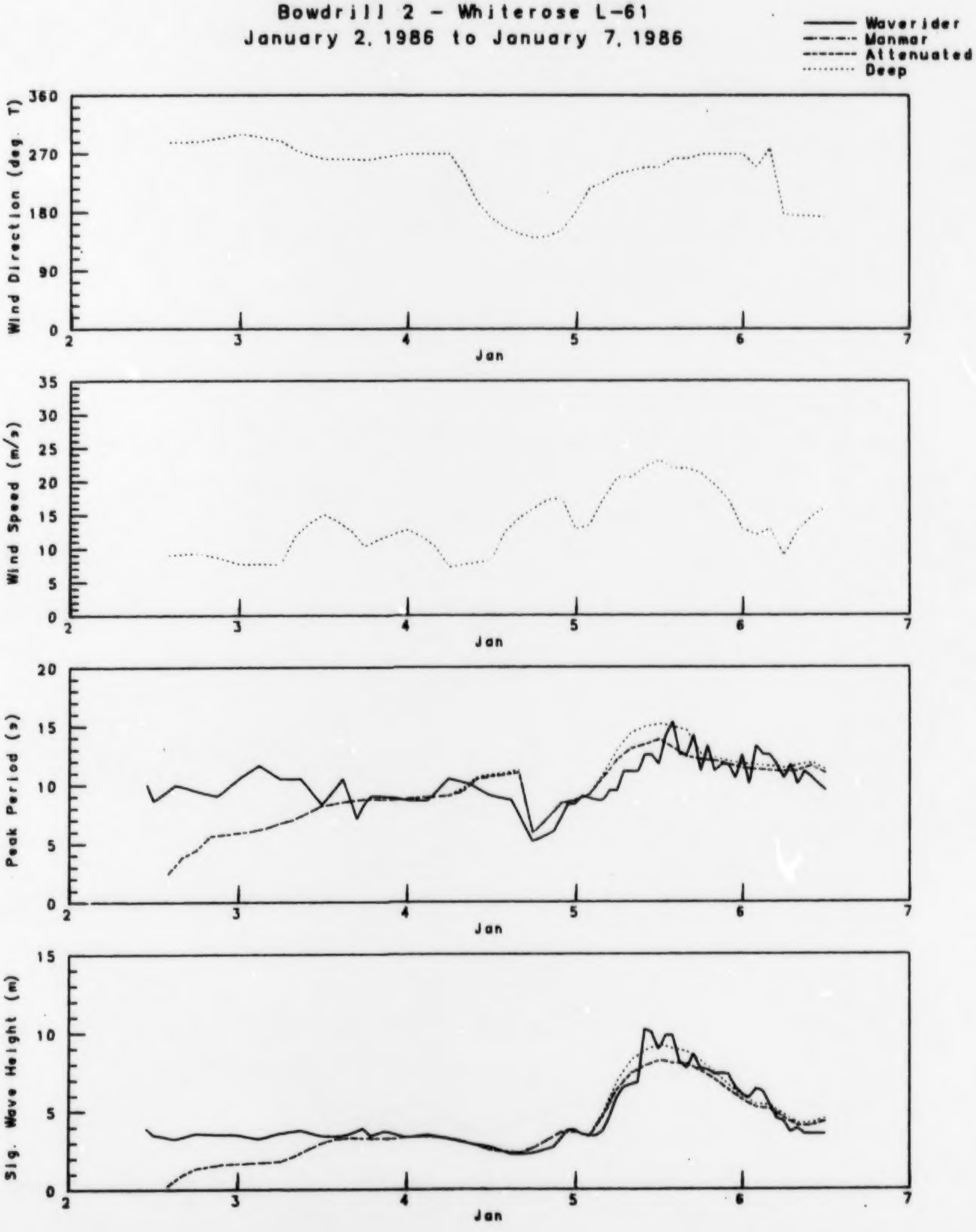


WIND/WAVE VERIFICATION FOR STORM 11

Grand Banks - Grid Point 3744

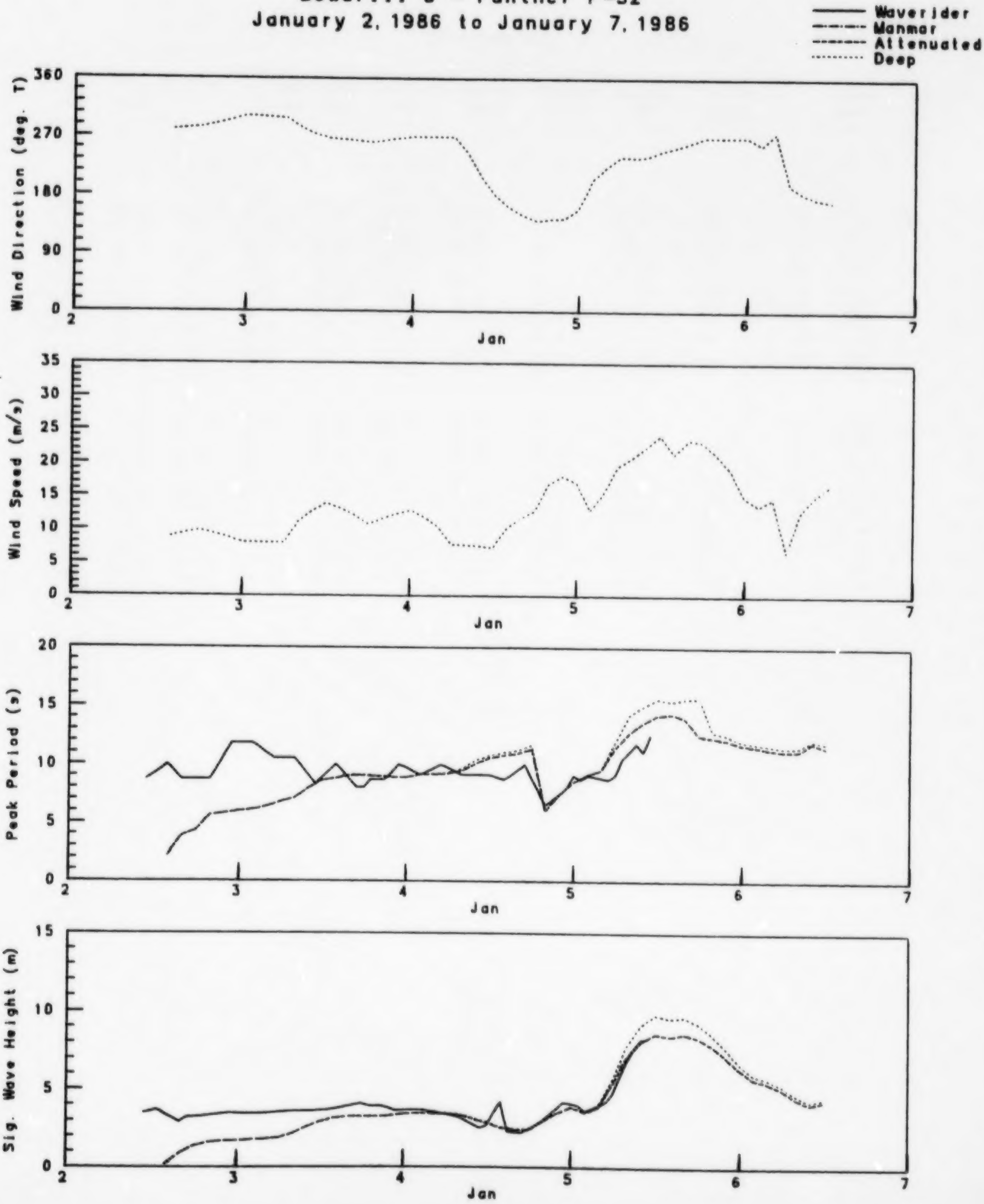
Bowdrill 2 - Whiterose L-61

January 2, 1986 to January 7, 1986



WIND/WAVE VERIFICATION FOR STORM 11

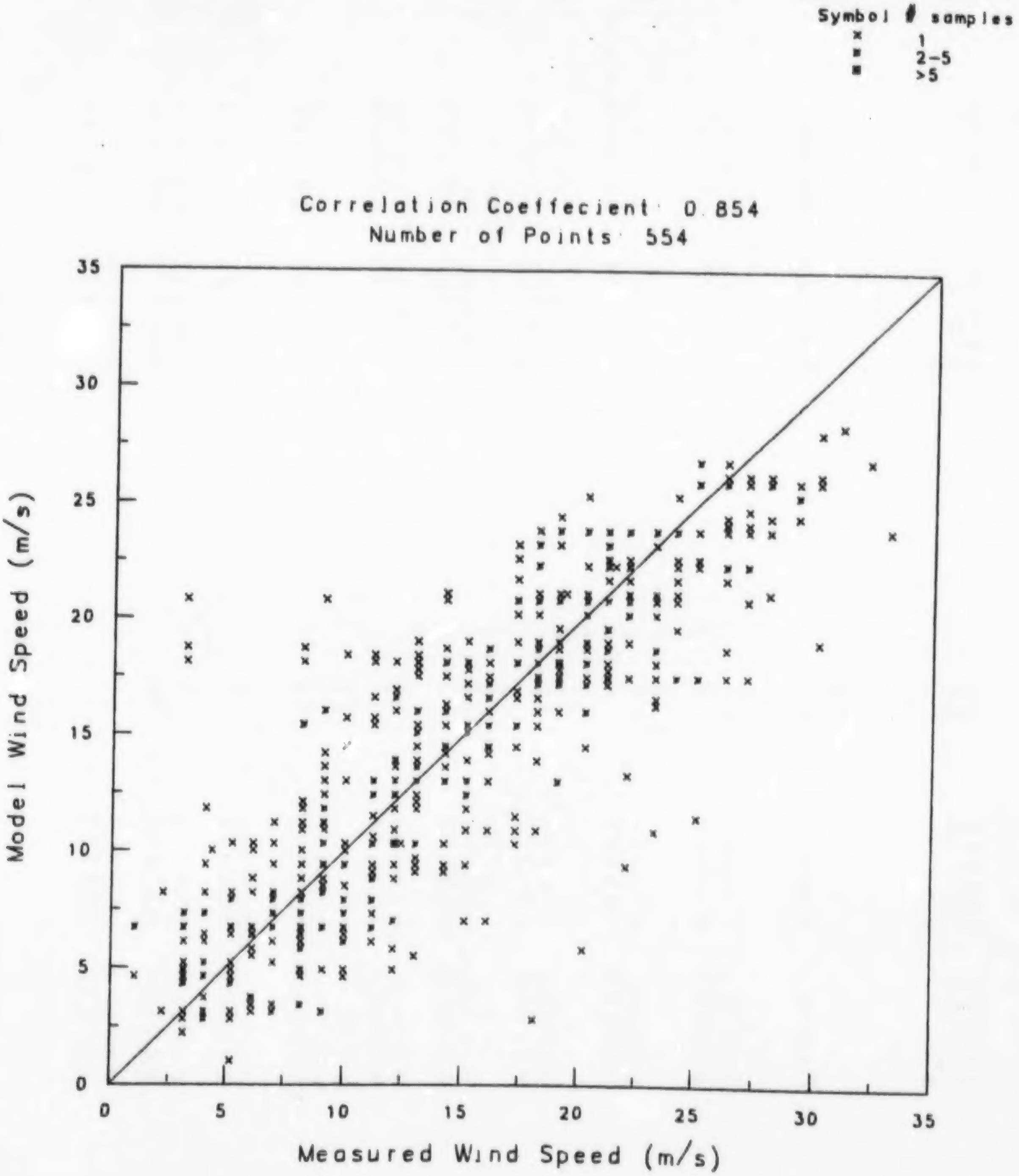
Grand Banks – Grid Point 3745
Bowdrill 3 – Panther P-52
January 2, 1986 to January 7, 1986



WIND STATISTICS

Var	Model Name	Num of Points	Average Obs	Standard Dev.	Average Model	Standard Dev	Mean Err	Absolute Mean Err	RMSE	Scatter Index	Corr Coef
WS	8201 - GB	57	18.32	7.26	17.81	5.53	-0.50	3.20	3.99	21.80	0.842
	8302 - SS	39	13.54	7.41	14.17	6.15	0.63	3.14	4.53	33.43	0.797
	8310 - SS	69	12.51	6.54	12.96	5.91	0.45	2.56	3.28	26.21	0.869
	8311 - SS	115	15.10	5.67	15.27	4.89	0.18	2.37	3.28	21.72	0.818
	8401 - SS	103	10.57	6.08	9.23	6.12	-1.34	2.94	3.81	36.06	0.829
	8501A - SS,GB	119	16.65	7.44	16.20	6.69	-0.45	3.19	4.38	26.29	0.815
	8501B - GB	15	19.80	8.40	18.65	8.08	-1.15	1.84	2.31	11.67	0.971
	8512 - GB	26	15.12	6.12	15.47	5.98	0.36	2.16	2.86	18.92	0.890
	8601 - GB	11	12.52	6.06	14.32	5.86	1.80	2.25	2.82	22.52	0.934
	Overall	554	14.56	7.16	14.33	6.61	-0.24	2.79	3.76	25.83	0.854
WD	8201 - GB	56	0.00	0.00	0.00	0.00	-0.19	23.56	39.90	0.00	0.000
	8302 - SS	39	0.00	0.00	0.00	0.00	-4.36	15.64	22.59	0.00	0.000
	8310 - SS	68	0.00	0.00	0.00	0.00	-3.76	23.02	33.94	0.00	0.000
	8311 - SS	115	0.00	0.00	0.00	0.00	-1.44	15.97	22.27	0.00	0.000
	8401 - SS	103	0.00	0.00	0.00	0.00	14.91	25.75	41.91	0.00	0.000
	8501A - SS,GB	119	0.00	0.00	0.00	0.00	9.07	32.46	54.60	0.00	0.000
	8501B - GB	15	0.00	0.00	0.00	0.00	-12.76	16.25	26.34	0.00	0.000
	8512 - GB	26	0.00	0.00	0.00	0.00	4.23	13.56	21.58	0.00	0.000
	8601 - GB	11	0.00	0.00	0.00	0.00	-24.27	143.91	164.46	0.00	0.000
	Overall	552	0.00	0.00	0.00	0.00	3.02	25.41	44.64	0.00	0.000

Model versus Measured Wind Values
All Storms and Regions



SCOTIAN SHELF STORMS - (DEEP water)

Var	Model Name	Num of Points	Average Obs	Standard Dev.	Average Model	Standard Dev	Mean Err	Absolute Mean Err	RMSE	Scatter Index	Corr Coef
HS	8302	14	4.35	1.65	4.29	1.96	-0.06	0.50	0.60	13.85	0.959
	8310	45	3.97	2.15	4.01	2.00	0.04	0.55	0.70	17.55	0.946
	8311	82	4.80	1.80	5.87	2.23	1.07	1.10	1.30	27.02	0.956
	8401	64	3.90	1.78	4.35	2.57	0.45	0.94	1.06	27.12	0.968
	8501a	83	4.40	1.93	5.29	2.37	0.88	1.04	1.32	30.06	0.916
	Overall	288	4.33	1.92	5.00	2.41	0.66	0.93	1.15	26.57	0.931
TP	8302	14	9.05	1.19	9.65	1.33	0.60	0.79	1.21	13.38	0.656
	8310	39	10.50	2.39	9.45	2.21	-1.05	1.52	2.04	19.41	0.715
	8311	80	10.21	2.46	11.62	2.52	1.41	1.59	2.02	19.83	0.830
	8401	64	10.00	2.07	10.44	2.69	0.44	1.37	1.64	16.38	0.811
	8501a	83	9.65	2.14	10.03	2.17	0.38	1.40	1.76	18.20	0.683
	Overall	280	9.98	2.25	10.48	2.50	0.50	1.44	1.83	18.35	0.730

SCOTIAN SHELF STORMS - (TMA Scaled)

Var	Model Name	Num of Points	Average Obs	Standard Dev.	Average Model	Standard Dev	Mean Err	Absolute Mean Err	RMSE	Scatter Index	Corr Coef
HS	8302	14	4.35	1.65	4.29	1.96	-0.06	0.50	0.60	13.85	0.959
	8310	45	3.97	2.15	4.01	2.00	0.04	0.55	0.70	17.55	0.946
	8311	82	4.80	1.80	5.38	1.87	0.58	0.64	0.75	15.66	0.967
	8401	64	3.90	1.78	4.15	2.35	0.24	0.75	0.84	21.59	0.961
	8501a	83	4.40	1.93	4.97	2.07	0.57	0.74	0.93	21.08	0.935
	Overall	288	4.33	1.92	4.72	2.14	0.39	0.67	0.81	18.75	0.944
TP	8302	14	9.05	1.19	9.65	1.33	0.60	0.79	1.21	13.38	0.656
	8310	39	10.50	2.39	9.45	2.21	-1.05	1.52	2.04	19.41	0.715
	8311	80	10.21	2.46	10.92	2.10	0.71	1.16	1.52	14.87	0.839
	8401	64	10.00	2.07	10.22	2.50	0.22	1.24	1.49	14.92	0.808
	8501a	83	9.65	2.14	9.79	1.98	0.14	1.28	1.64	16.98	0.689
	Overall	280	9.98	2.25	10.16	2.22	0.18	1.24	1.62	16.21	0.741

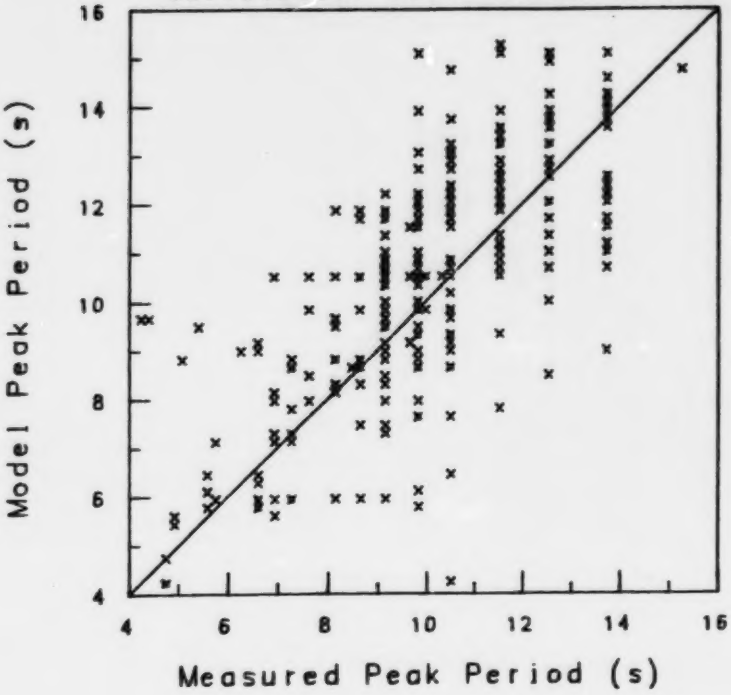
Model versus Measured Wave Values

Scotian Shelf

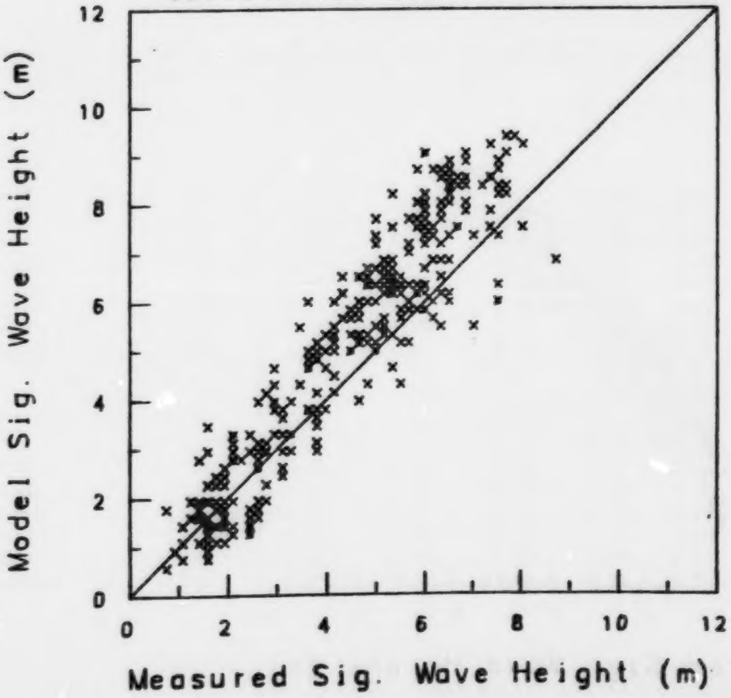
Deep Water

x 1
■ 2–5
■ >5

Number of Points: 280
Correlation Coeffecient: 0.730



Number of Points: 288
Correlation Coeffecient: 0.931



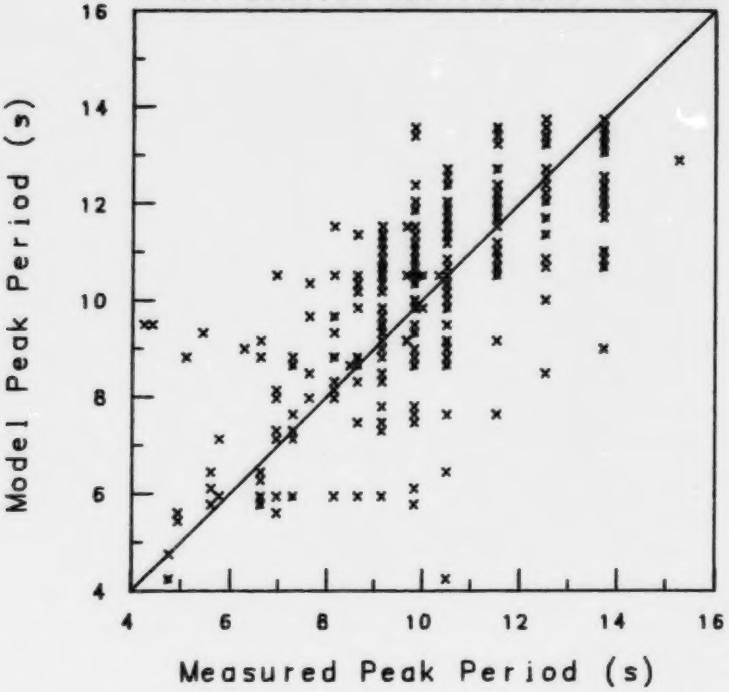
Model versus Measured Wave Values

Scotian Shelf

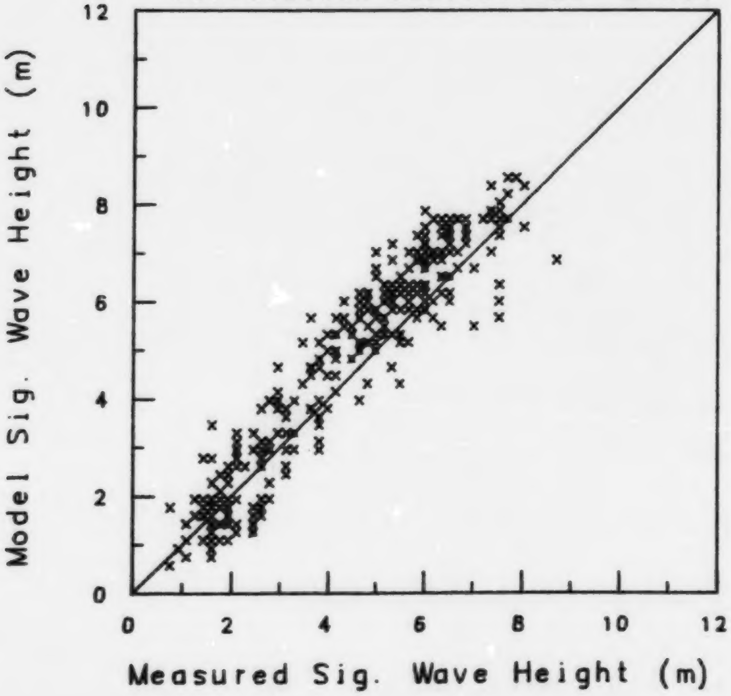
TMA Scaled

× 1
× 2-5
■ >5

Number of Points: 280
Correlation Coeffecient: 0.741



Number of Points: 288
Correlation Coeffecient: 0.944



GRAND BANKS STORMS - (DEEP water)

Var	Model Name	Num of Points	Average Obs	Standard Dev.	Average Model	Standard Dev	Mean Err	Absolute Mean Err	RMSE	Scatter Index	Corr Coef
HS	8201	95	6.22	2.16	7.37	2.90	1.15	1.23	1.61	25.84	0.943
	8311	117	5.42	1.85	6.22	2.32	0.80	0.96	1.13	20.91	0.950
	8312	59	7.17	2.39	9.34	3.12	2.16	2.16	2.44	34.02	0.952
	8501a	119	5.47	1.33	7.11	2.10	1.64	1.71	2.01	36.67	0.867
	8501b	128	6.61	2.08	8.27	2.64	1.65	1.69	1.89	28.55	0.953
	8512	68	5.92	2.03	6.73	2.03	0.80	1.43	1.66	28.10	0.740
	8601	31	5.30	2.21	5.45	2.26	0.15	0.56	0.74	13.95	0.948
	Overall	617	6.02	2.05	7.31	2.70	1.29	1.44	1.75	29.07	0.912
TP	8201	95	11.91	1.83	12.85	2.71	0.94	2.05	2.50	21.02	0.538
	8311	113	13.05	1.61	12.82	1.87	-0.23	1.35	1.83	14.01	0.465
	8312	61	13.70	2.05	14.61	1.72	0.91	1.20	1.48	10.83	0.820
	8501a	118	11.44	2.11	13.57	2.23	2.12	2.17	2.70	23.61	0.706
	8501b	128	12.14	1.49	13.04	2.44	0.89	1.65	2.02	16.67	0.671
	8512	68	11.23	1.83	12.27	1.34	1.04	1.63	1.94	17.29	0.500
	8601	31	10.22	2.02	11.38	2.45	1.15	1.55	1.91	18.70	0.783
	Overall	614	12.10	2.02	13.06	2.30	0.96	1.70	2.16	17.85	0.607

GRAND BANKS STORMS - (TMA Scaled)

Var	Model Name	Num of Points	Average Obs	Standard Dev.	Average Model	Standard Dev	Mean Err	Absolute Mean Err	RMSE	Scatter Index	Corr Coef
HS	8201	95	6.22	2.16	6.67	2.26	0.45	0.68	0.88	14.21	0.942
	8311	117	5.42	1.85	5.75	2.02	0.33	0.58	0.70	13.00	0.952
	8312	59	7.17	2.39	8.15	2.33	0.98	1.07	1.26	17.60	0.943
	8501a	119	5.47	1.33	6.46	1.74	0.99	1.09	1.32	24.11	0.870
	8501b	128	6.61	2.08	7.56	2.22	0.95	1.00	1.16	17.52	0.954
	8512	68	5.92	2.03	6.29	1.72	0.37	1.15	1.40	23.66	0.751
	8601	31	5.30	2.21	5.11	1.93	-0.18	0.52	0.76	14.34	0.946
	Overall	617	6.02	2.05	6.66	2.21	0.64	0.89	1.11	18.40	0.913
TP	8201	95	11.91	1.83	12.29	2.31	0.38	1.65	2.07	17.39	0.538
	8311	113	13.05	1.61	12.17	1.72	-0.88	1.44	1.98	15.16	0.434
	8312	61	13.70	2.05	13.94	1.55	0.24	0.99	1.17	8.53	0.833
	8501a	118	11.44	2.11	12.73	1.87	1.29	1.46	1.95	17.04	0.735
	8501b	128	12.14	1.49	12.43	2.28	0.29	1.31	1.76	14.52	0.648
	8512	68	11.23	1.83	11.83	1.22	0.60	1.36	1.70	15.10	0.521
	8601	31	10.22	2.02	10.83	1.95	0.61	1.22	1.45	14.21	0.780
	Overall	614	12.10	2.02	12.42	2.04	0.33	1.39	1.82	15.07	0.609

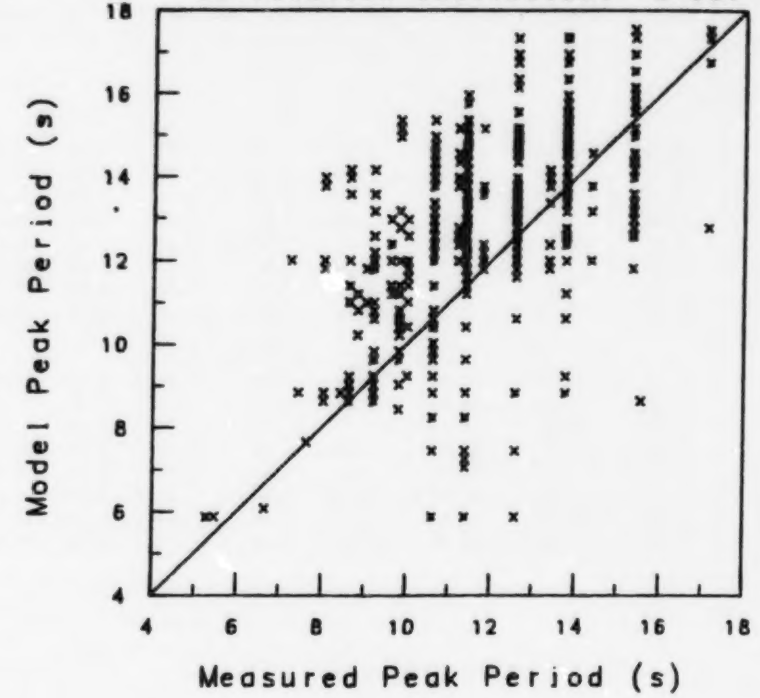
Model versus Measured Wave Values

Grand Banks

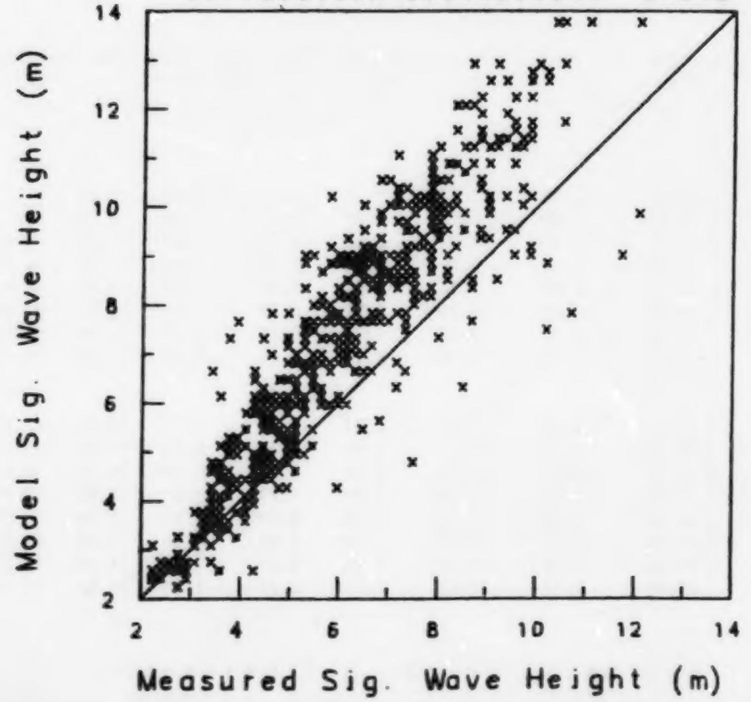
Deep Water

× 1
× 2-5
■ >5

Number of Points: 614
Correlation Coeffecient: 0.607



Number of Points: 617
Correlation Coeffecient: 0.912



Model versus Measured Wave Values

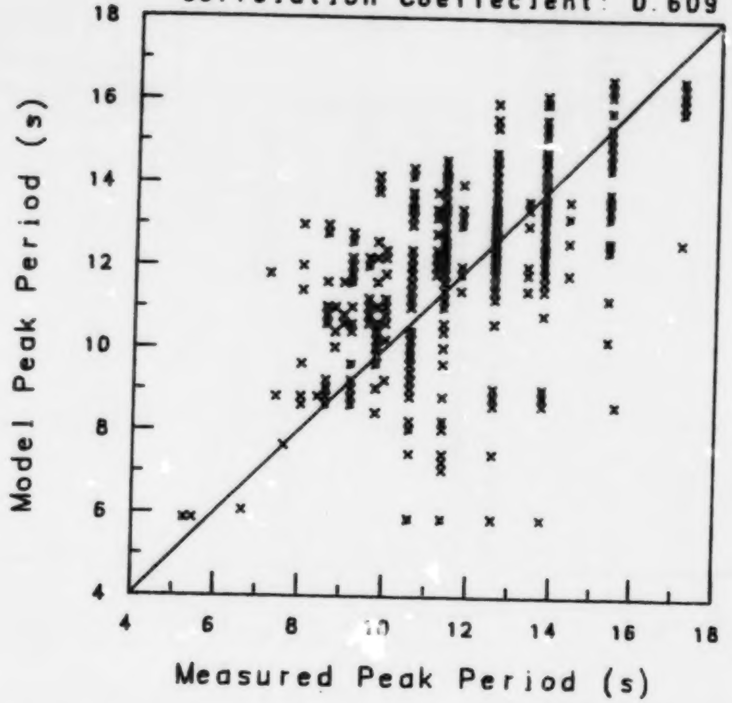
Grand Banks

TMA Scaled

× 1
▪ 2-5
■ >5

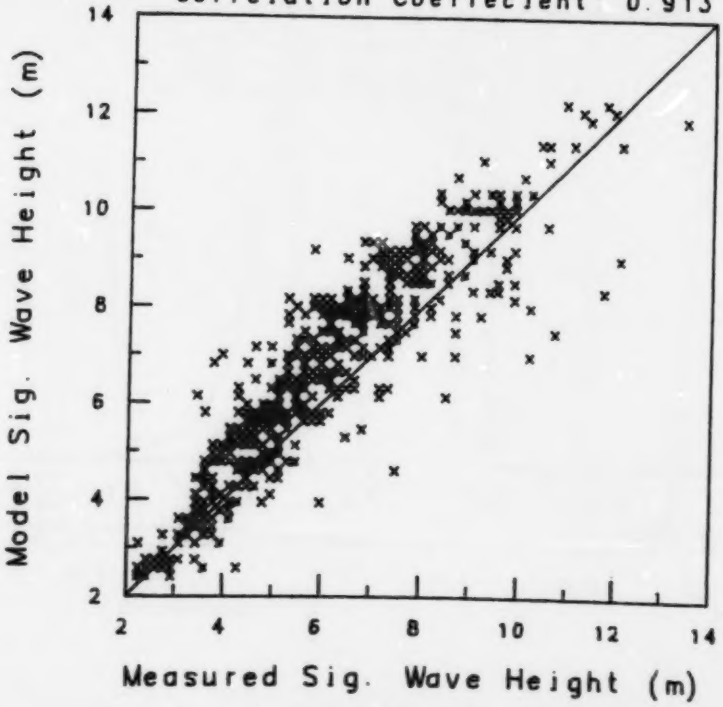
Number of Points: 614

Correlation Coeffecient: 0.609

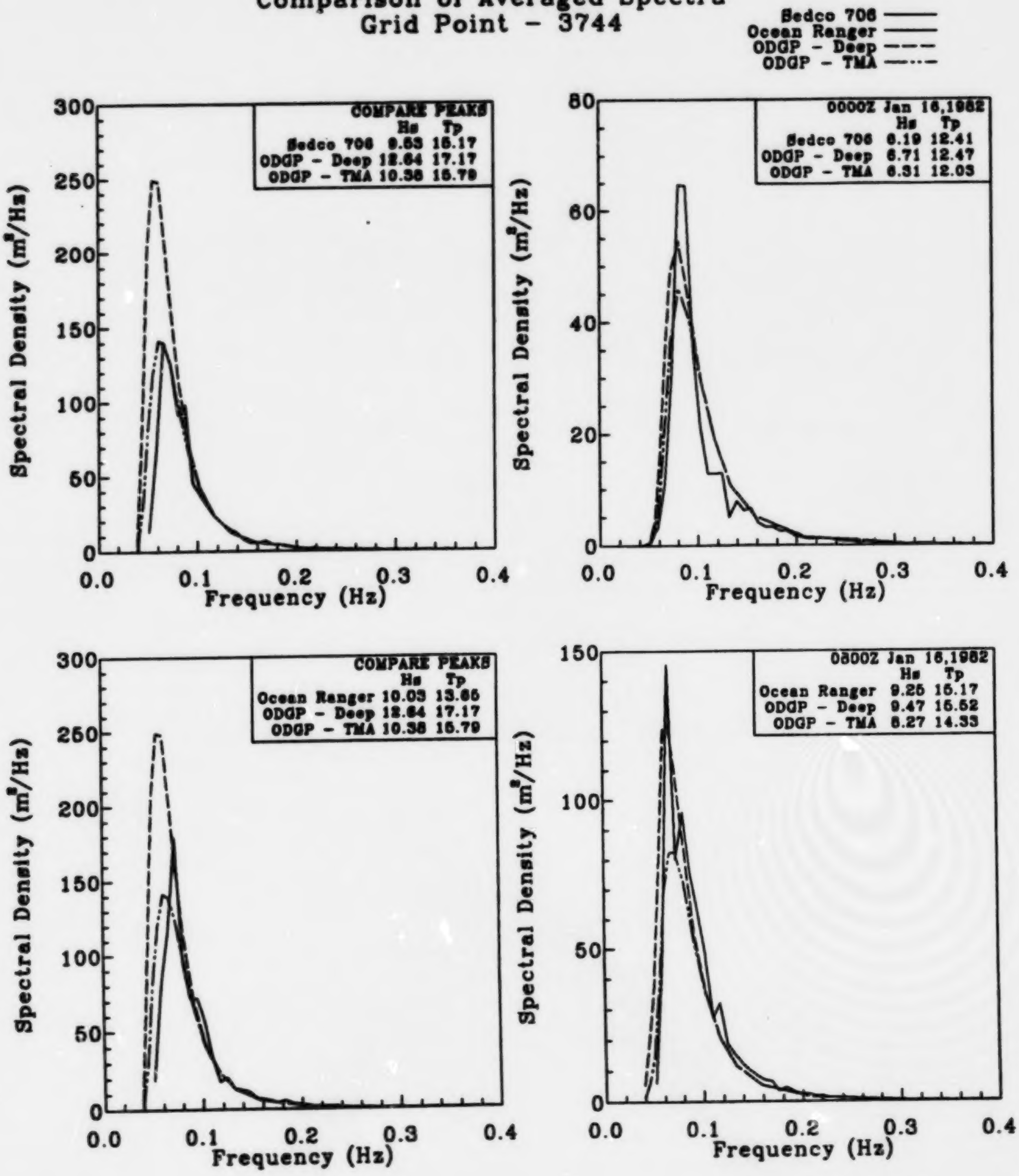


Number of Points: 617

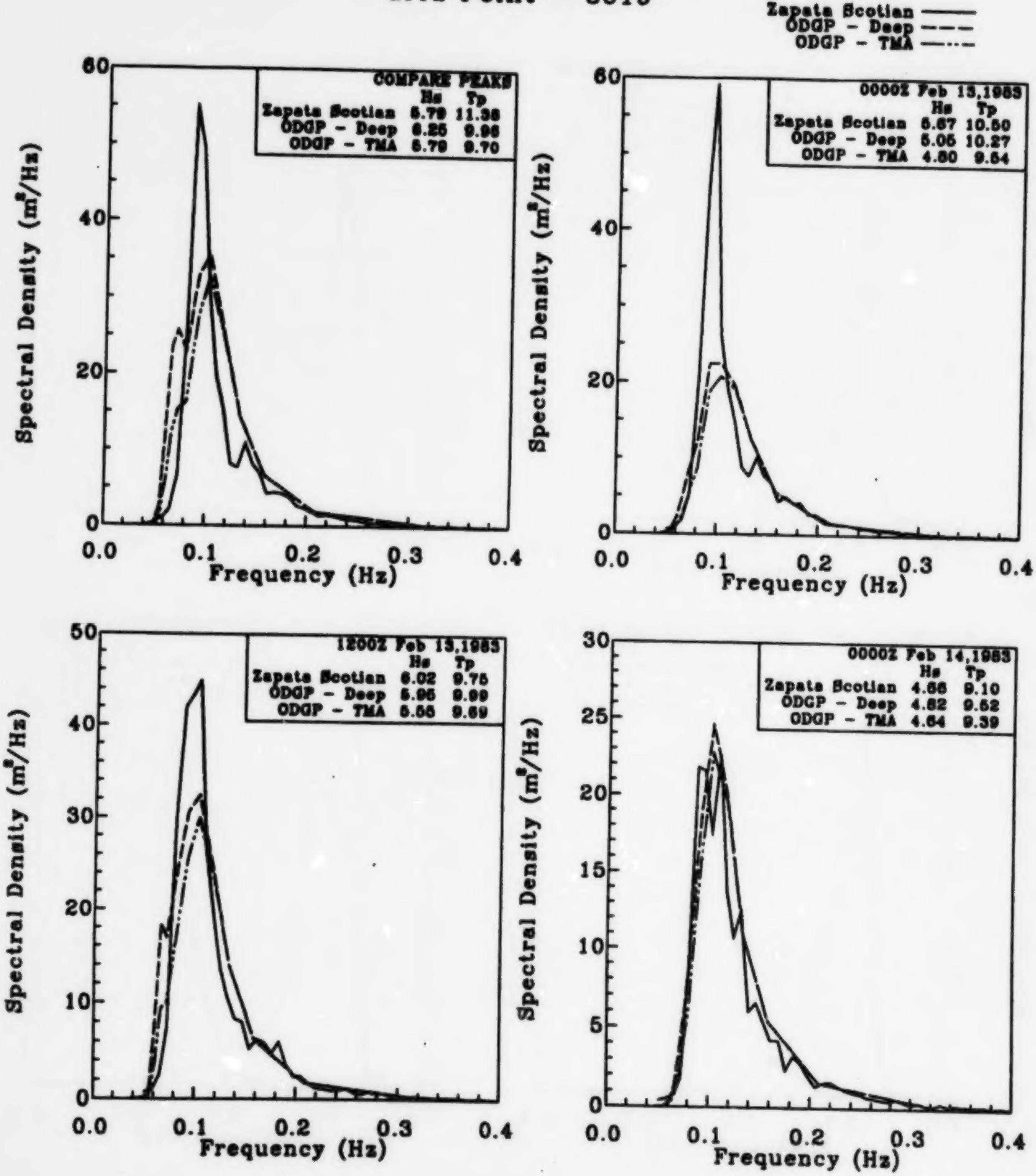
Correlation Coeffecient: 0.913



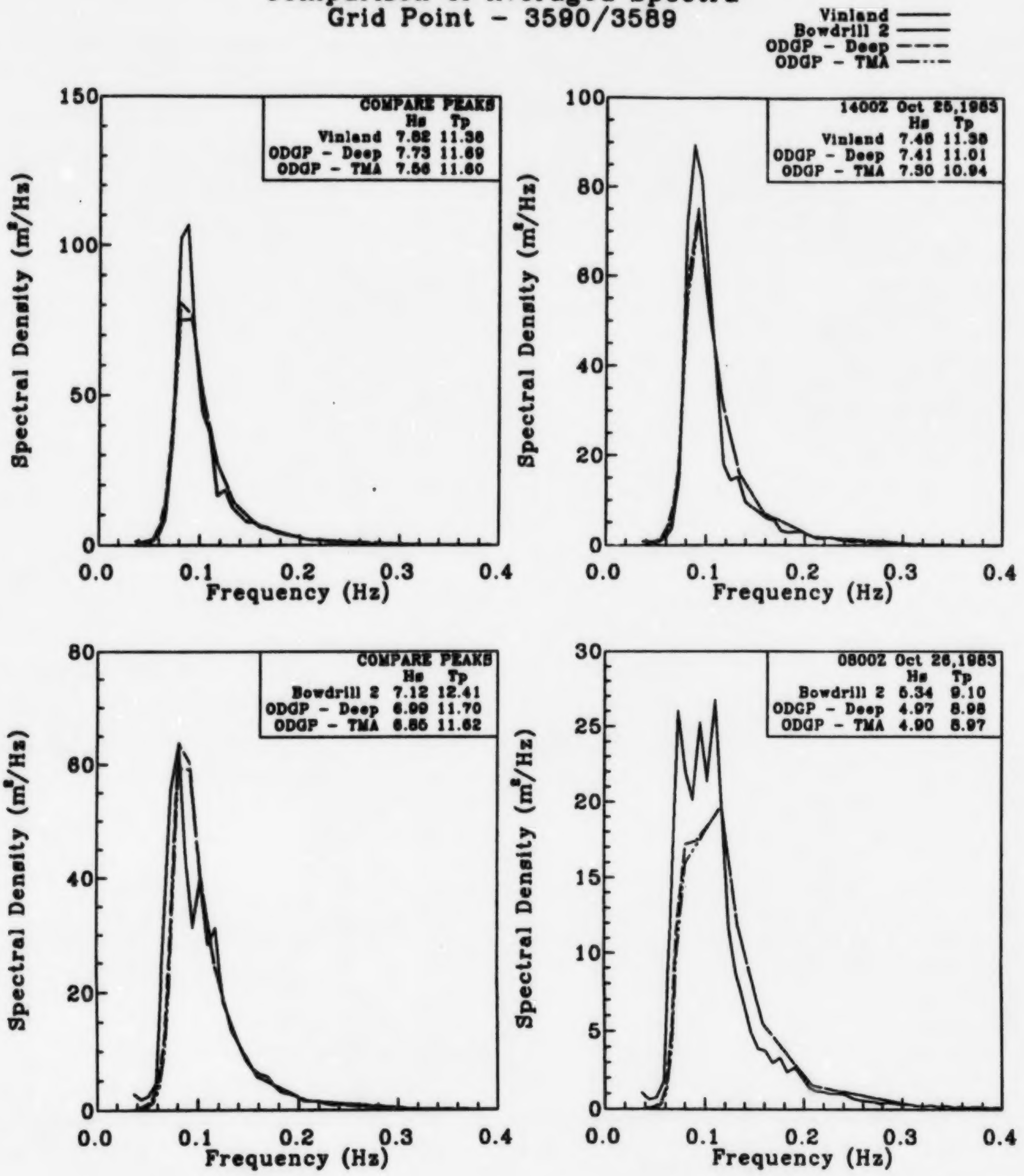
Storm 1 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3744



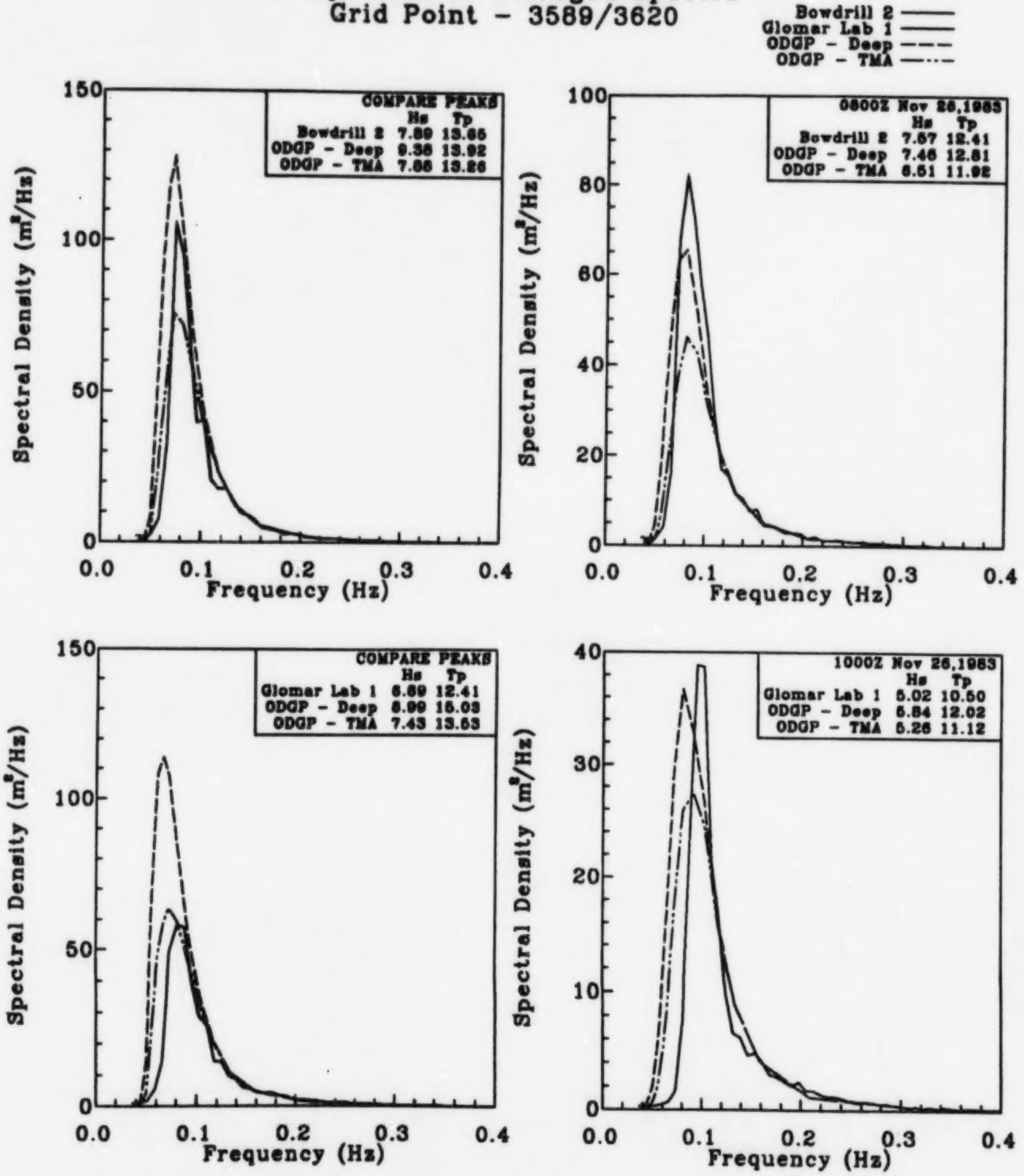
Storm 3 - Scotian Shelf
Comparison of Averaged Spectra
Grid Point - 3619



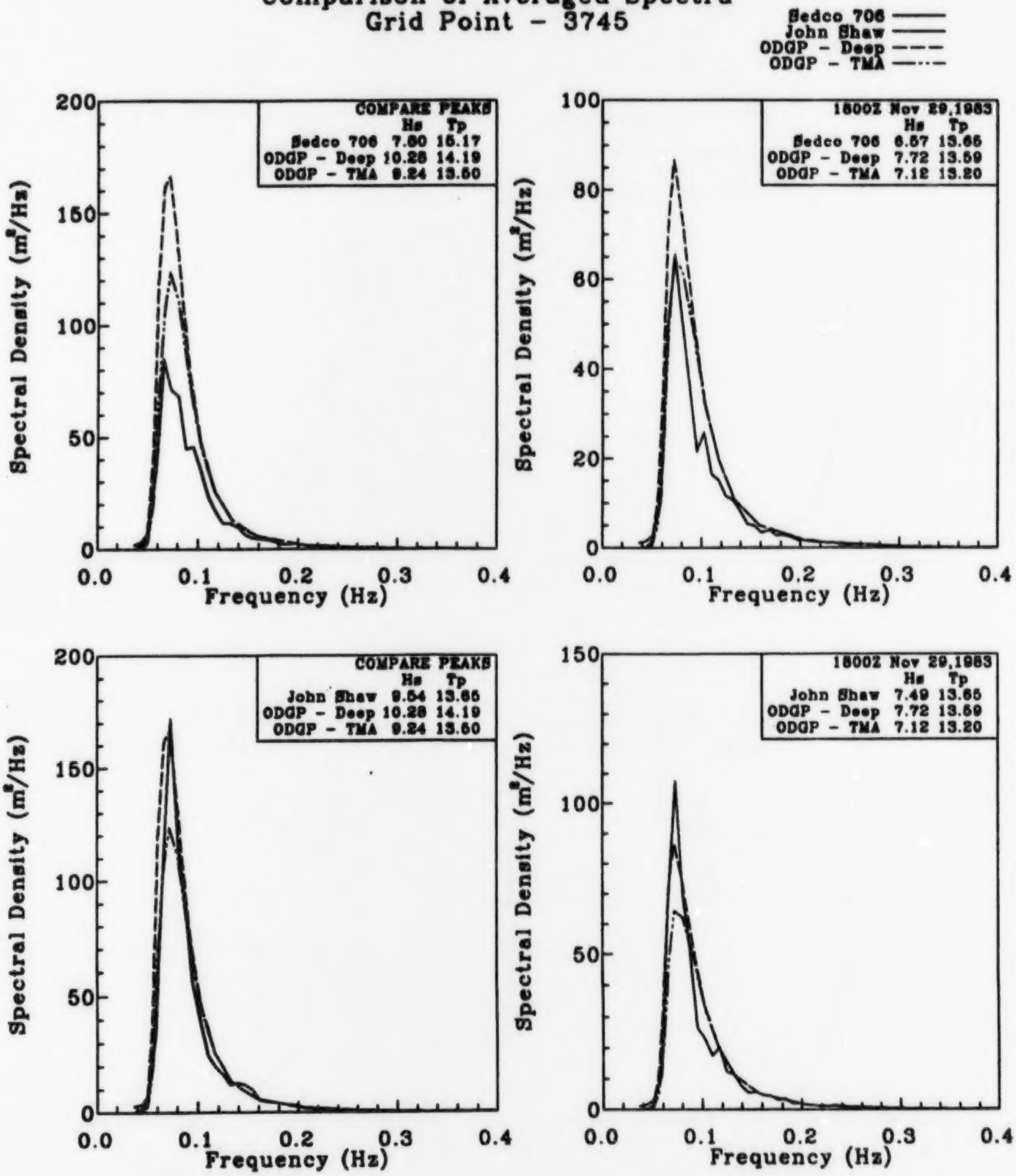
Storm 4 - Scotian Shelf
Comparison of Averaged Spectra
Grid Point - 3590/3589



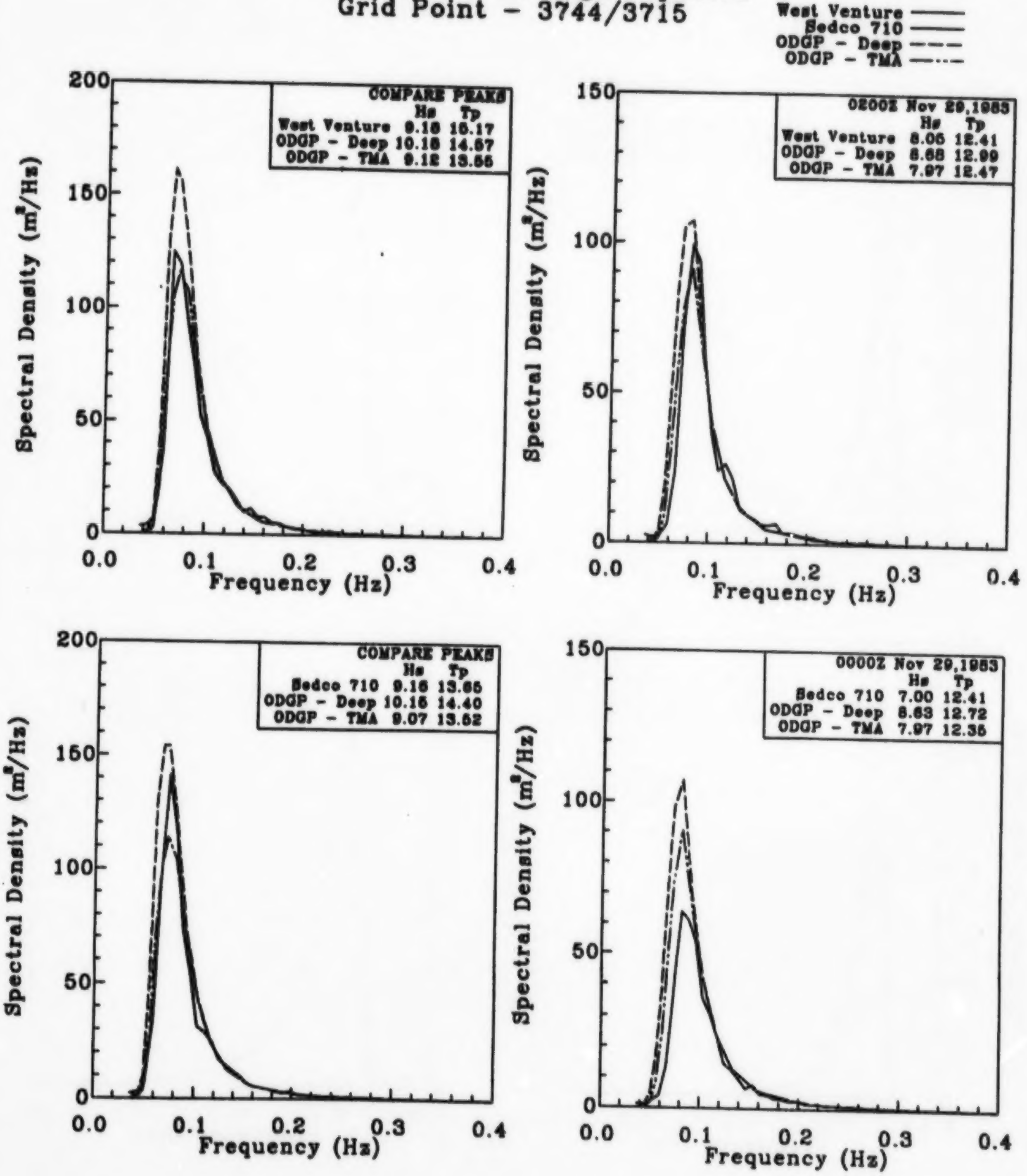
Storm 5 - Scotian Shelf
Comparison of Averaged Spectra
Grid Point - 3589/3620



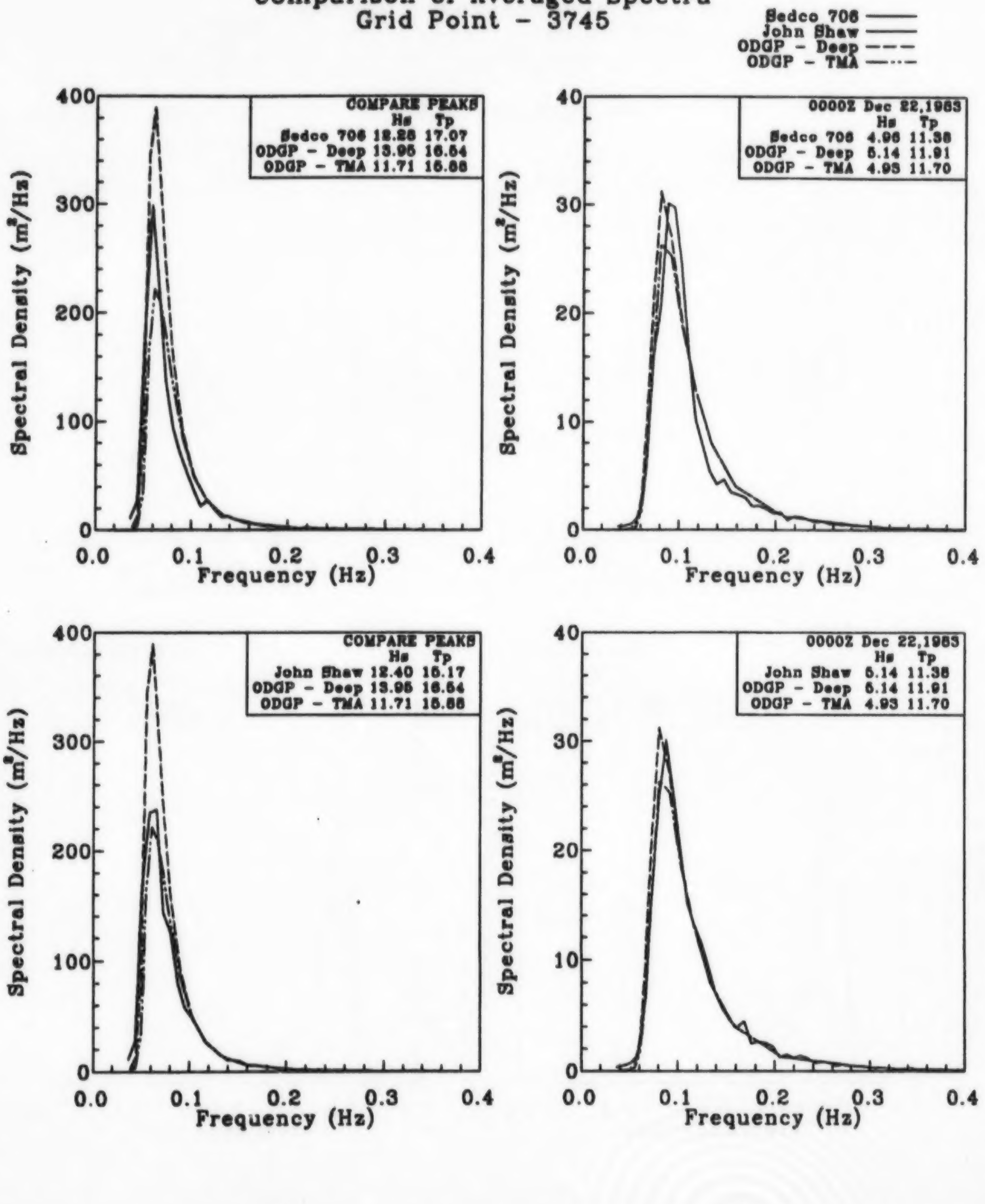
Storm 5 – Grand Banks
Comparison of Averaged Spectra
Grid Point – 3745



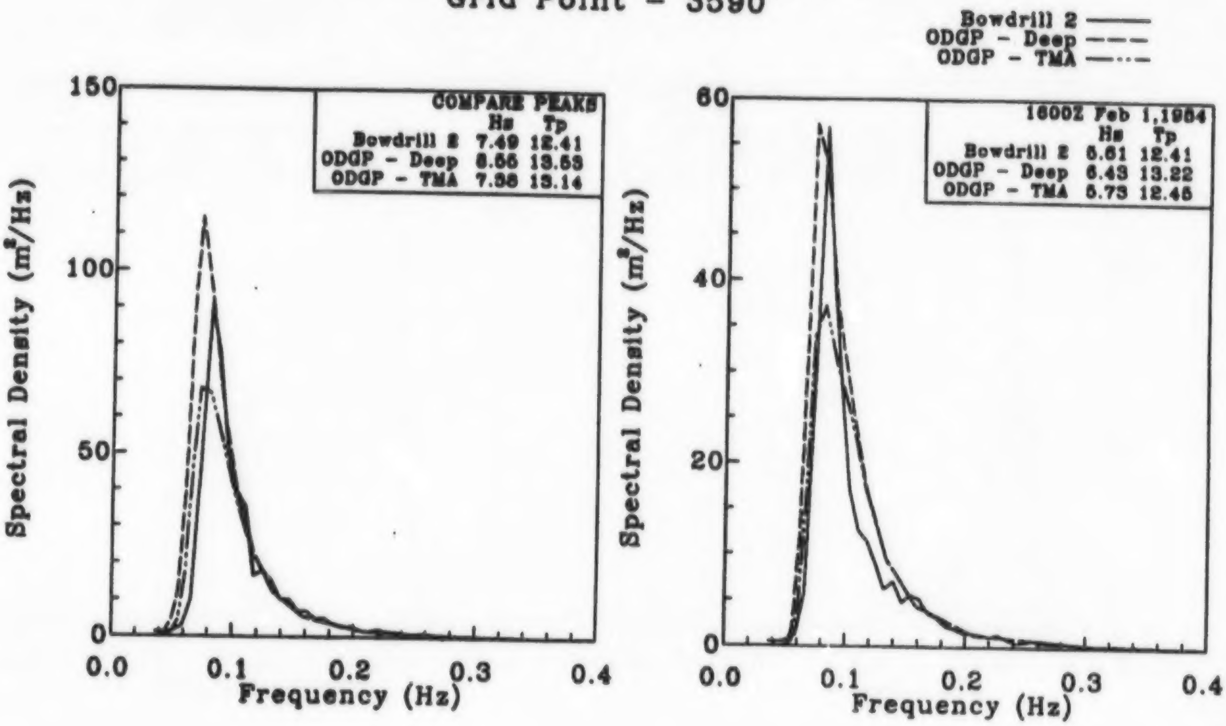
Storm 5 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3744/3715



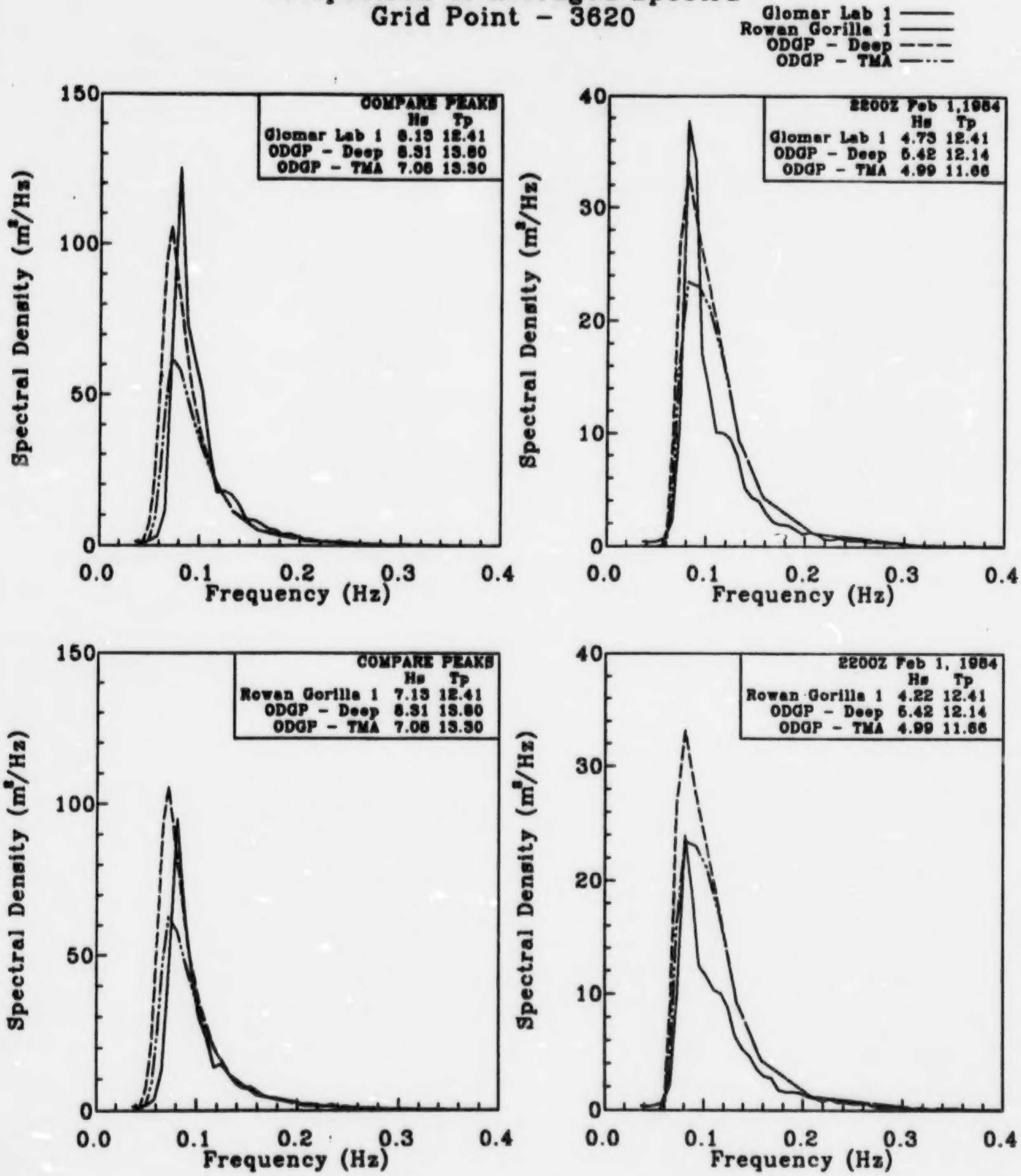
Storm 6 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3745



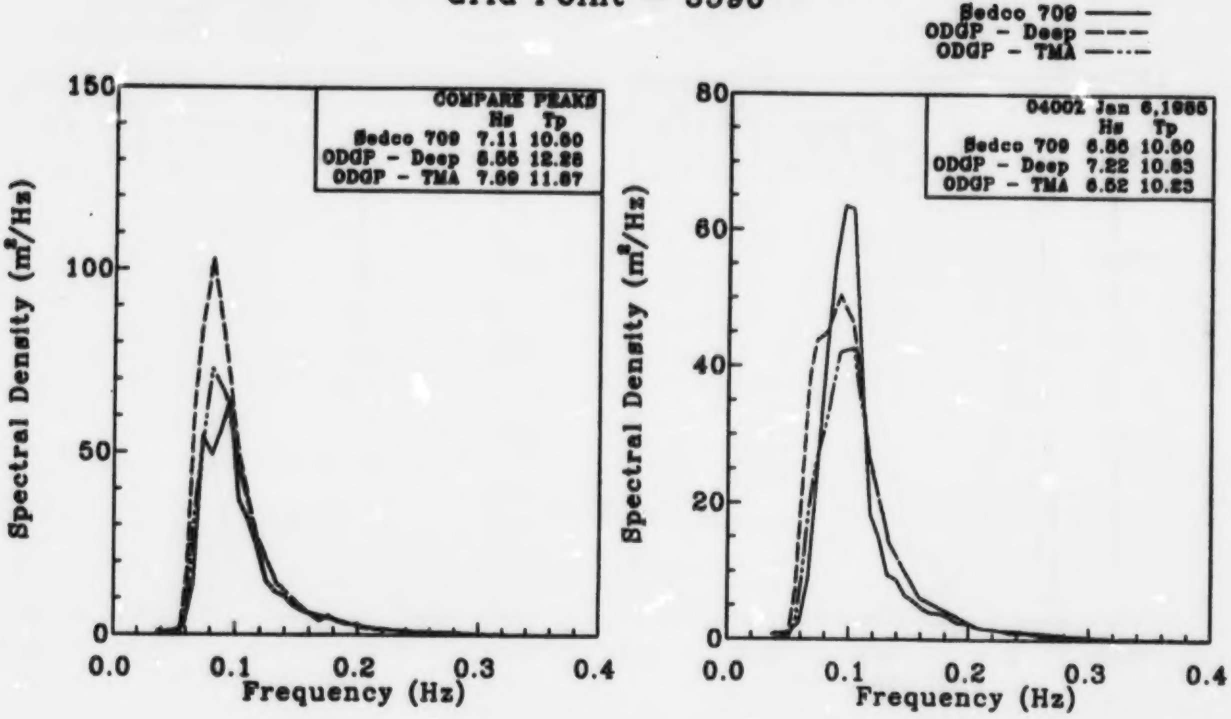
Storm 7 - Scotian Shelf
Comparison of Averaged Spectra
Grid Point - 3590



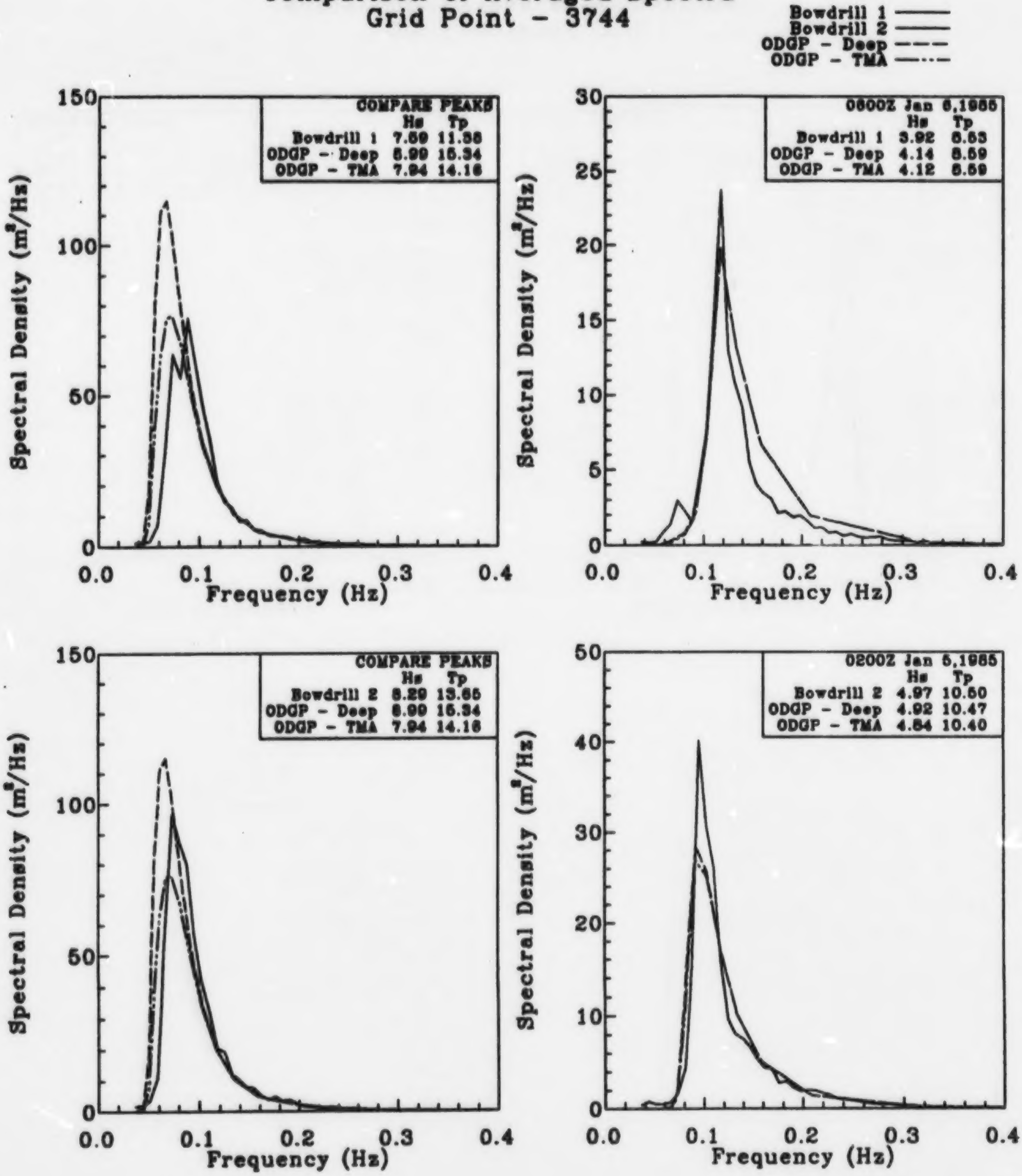
Storm 7 - Scotian Shelf
Comparison of Averaged Spectra
Grid Point - 3620



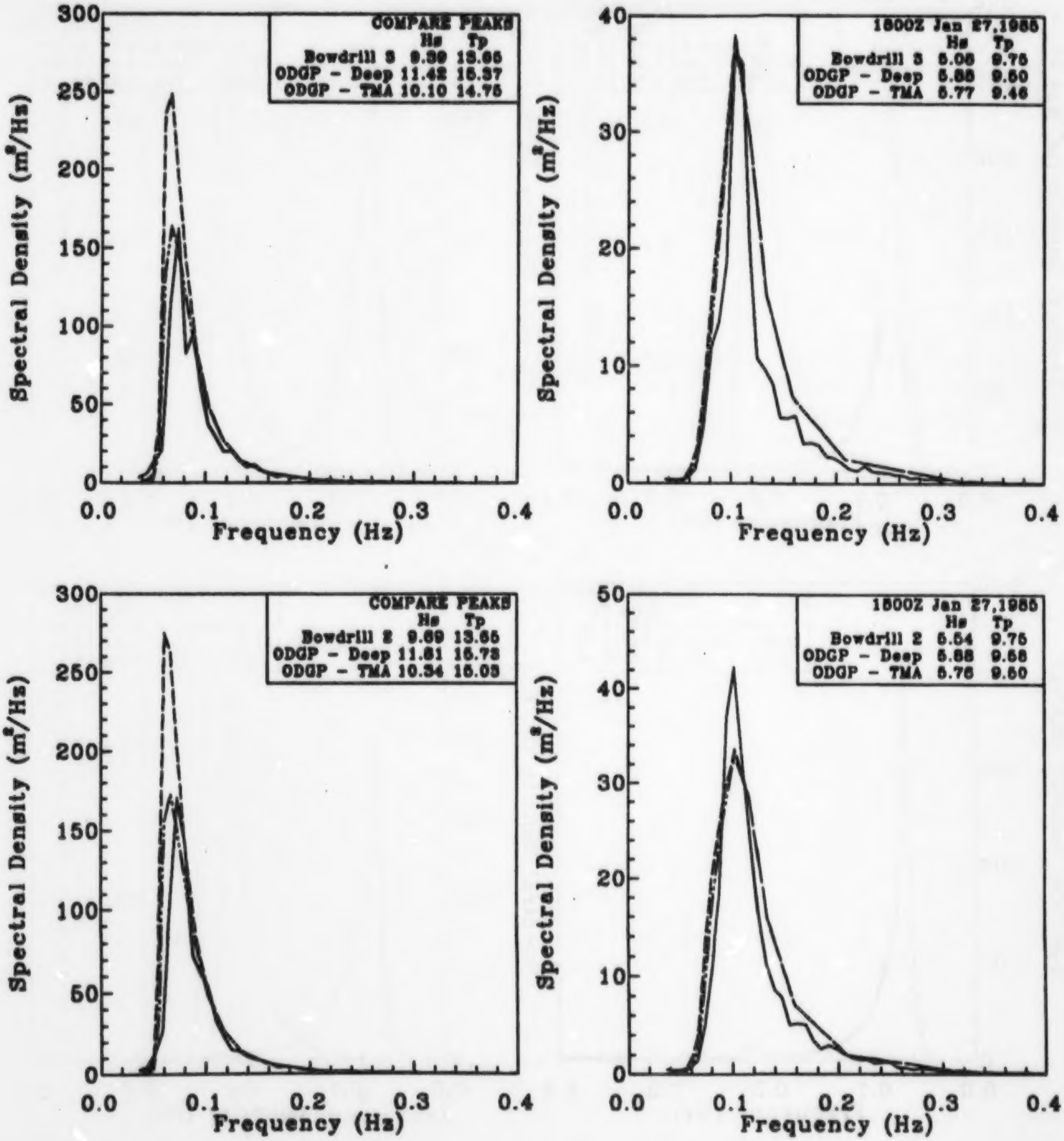
Storm 8 - Scotian Shelf
Comparison of Averaged Spectra
Grid Point - 3590



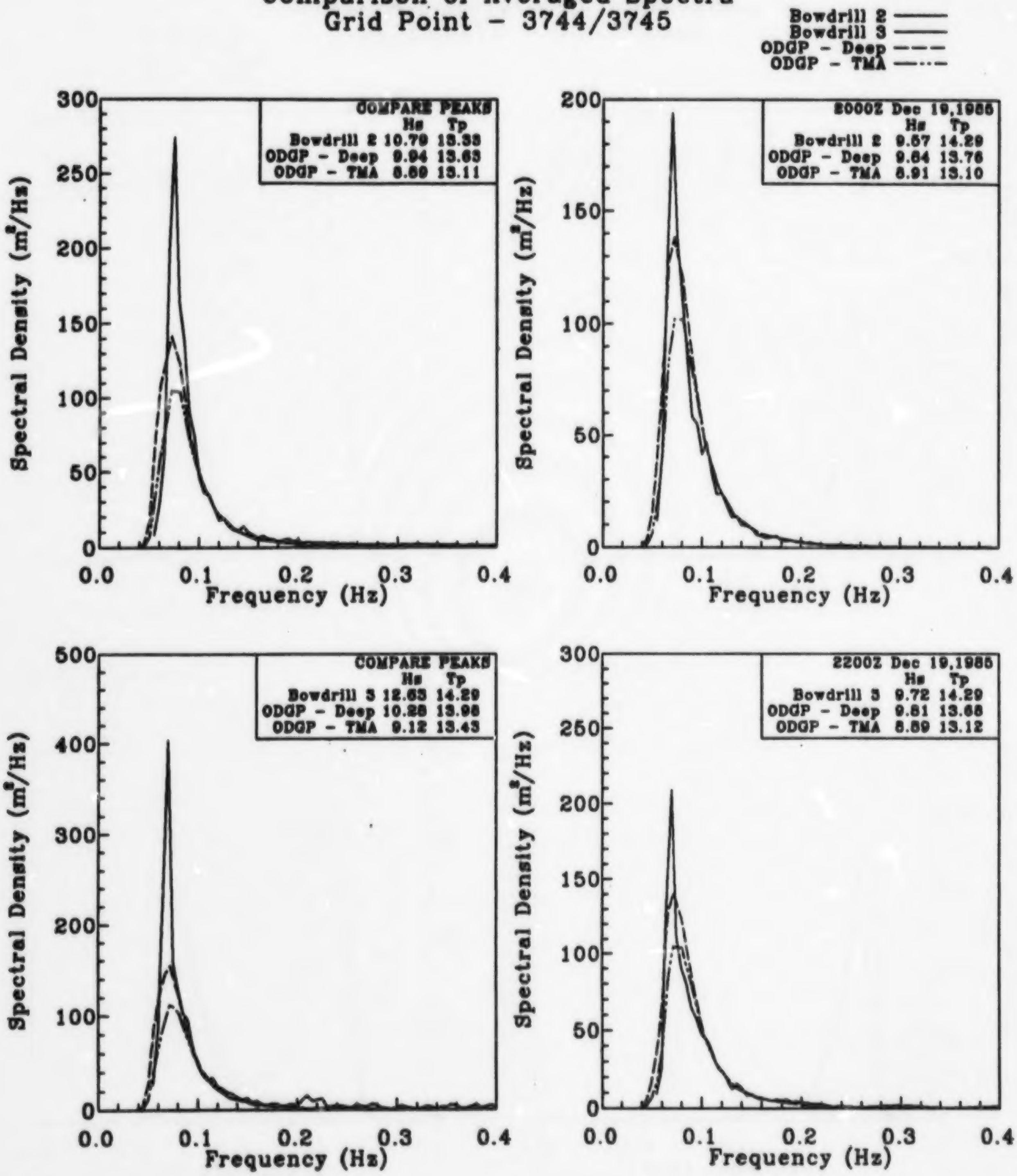
Storm 8 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3744

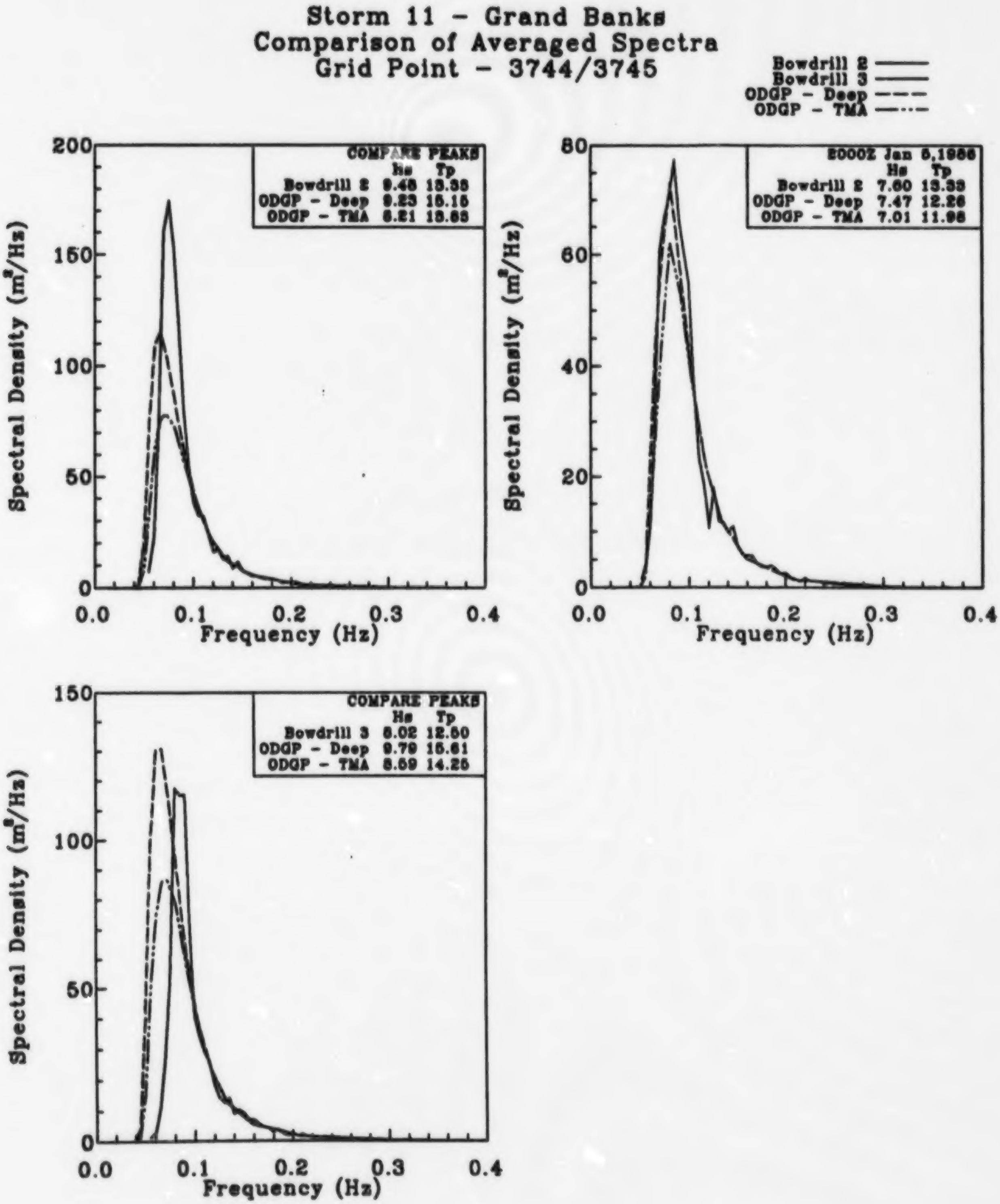


Storm 9 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3744/3745



Storm 10 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3744/3745





Storm 11 - Grand Banks
Comparison of Averaged Spectra
Grid Point - 3744/3745

APPENDIX D

EXTREMAL ANALYSIS RESULTS

List of 68 Storms Sorted by H_s - Georges Bank

		STORM	GRID PT 3498			GRID PT 3590			GRID PT 3744		
MCL#	REGION	START END	Hs (m)	Tp (s)	VMD (to)	Hs (m)	Tp (s)	VMD (to)	Hs (m)	Tp (s)	VMD (to)
241	SS	71030300-71030700	11.0	15.2	72.	10.5	16.9	61.	7.4	12.2	158.
189	SS,GB	67022100-67022500	10.1	13.3	90.	10.3	14.7	56.	12.6	16.8	49.
404	SS	78010812-78011212	9.1	13.8	46.	8.4	13.8	38.	5.5	13.8	55.
172	SS,GB	66012612-66013012	8.9	12.2	102.	7.8	14.5	81.	9.6	12.5	304.
195	SS	67042700-67050200	8.9	12.3	216.	8.0	12.1	289.	3.1	13.0	6.
377	SS,GB	76031600-76032000	8.7	12.3	96.	10.2	14.5	65.	12.4	17.2	65.
147	SS	64113000-64120312	8.6	11.9	98.	10.0	14.4	47.	6.2	13.6	62.
495	SS,GB	83112400-83113012	8.4	12.7	84.	9.7	14.6	66.	10.2	14.6	155.
464	SS,GB	81121500-81121912	8.3	13.1	66.	9.6	14.6	62.	9.4	15.6	69.
NEW	EB	80011412-80011812	8.3	13.3	248.	7.4	12.0	271.	3.2	8.2	189.
303	SS,EB	73032112-73032500	8.2	12.7	236.	7.7	11.9	251.	4.8	10.7	288.
95	SS	62030600-62030912	8.2	12.0	249.	6.2	11.8	247.	5.2	10.8	191.
506	SS	84032812-84040112	8.2	13.1	201.	7.5	11.8	256.	6.8	11.0	98.
102	SS	62111412-62111912	8.1	11.9	198.	7.2	11.4	278.	6.3	12.5	13.
453	SS	81031512-81032000	8.0	11.8	92.	9.3	14.6	36.	8.4	14.1	59.
465	SS,GB	81122912-82010300	8.0	11.9	151.	8.6	12.1	146.	10.2	14.7	187.
310	SS	73110100-73110512	7.9	12.0	99.	8.6	13.4	70.	7.6	14.8	65.
124	SS,GB	63121900-63122118	7.6	11.6	149.	9.4	13.3	74.	9.1	15.5	56.
433	SS,GB	80020612-80021012	7.6	11.3	209.	7.6	11.7	225.	8.1	12.9	208.
467	SS,GB	82011300-82011900	7.6	11.0	102.	9.1	13.4	58.	12.6	17.2	58.
260	SS,GB	72021812-72022200	7.5	13.5	71.	7.7	13.3	19.	7.2	13.1	15.
282	SS,GB	72121512-72121912	7.5	11.7	114.	8.6	13.5	84.	8.8	15.1	70.
129	SS,GB	64011212-64011718	7.3	11.7	178.	7.0	10.8	157.	10.9	14.3	95.
502	SS	84012912-84020312	7.3	11.6	59.	8.6	13.5	57.	6.3	12.2	70.
442	SS,GB	80111812-80112212	7.3	11.2	153.	8.0	11.2	132.	9.5	12.3	134.
421	GB	79020300-79020712	7.1	11.4	116.	6.7	11.8	102.	6.1	12.4	167.
451	SS	81030500-81031000	7.0	13.1	213.	8.9	13.9	230.	8.7	13.7	234.
223	SS	69122600-69123012	7.0	11.9	80.	7.5	12.0	330.	6.4	11.2	143.
70	SS,GB	61011912-61012312	7.0	11.9	306.	8.9	14.9	78.	11.1	16.6	54.
443	SS	80112106-80112418	7.0	10.7	170.	6.8	11.0	229.	6.0	10.9	273.
325	SS,GB	74020400-74020800	6.9	10.8	169.	8.1	10.7	94.	7.0	10.9	114.
463	SS,EB	81120412-81120812	6.9	10.8	109.	6.5	12.8	358.	4.1	14.5	30.
200	SS,GB	68010418-68010800	6.8	10.4	143.	8.4	12.3	97.	10.1	15.3	68.
235	SS,GB	70122600-70123000	6.8	10.7	126.	9.9	14.7	40.	7.9	15.7	47.
215	SS	69020900-69021218	6.7	11.5	332.	7.2	11.8	329.	5.6	11.3	345.
326	SS	74021612-74022000	6.7	10.5	104.	8.1	12.8	6.	6.5	12.6	21.
169	SS,GB	66010812-66011212	6.6	10.7	163.	7.6	11.8	168.	8.8	12.4	171.
487	SS,GB	83021000-83021500	6.4	10.4	285.	6.3	10.1	142.	8.8	11.9	109.
174	SS,GB	66021318-66021812	6.3	10.8	60.	6.9	12.6	74.	12.0	15.1	138.
512	SS,GB	85010400-85010900	6.3	10.6	143.	8.6	12.5	93.	9.0	15.3	64.
526	GB	86010212-86010612	6.3	10.6	126.	7.2	11.0	61.	9.2	15.1	61.
106	SS	62123000-63010218	6.3	10.6	121.	5.9	10.5	328.	6.4	11.8	304.
132	SS,GB	64020800-64021018	6.1	11.0	94.	8.8	12.3	69.	9.3	14.6	63.
54	SS,GB	60010900-60011300	6.1	10.5	170.	7.5	12.2	163.	8.8	12.2	116.
329	SS,GB	74031012-74031412	6.1	10.5	148.	8.4	11.6	158.	10.0	14.6	37.
384	SS,GB	76110512-76111000	5.9	10.7	163.	7.3	12.3	83.	7.0	13.7	66.
85	SS,GB	61121412-61121912	5.8	10.4	155.	6.8	11.0	153.	10.3	13.5	111.
488	SS,GB	83021506-83021900	5.8	11.1	258.	5.3	10.1	205.	10.3	13.2	210.
523	GB	85121512-85122112	5.7	10.4	115.	6.7	11.2	87.	9.9	13.6	86.
386	SS	76111812-76112300	5.6	10.4	116.	7.7	11.4	98.	7.4	11.9	324.
151	GB	65012112-65012512	5.6	9.4	207.	4.6	9.2	316.	7.4	12.9	136.
140	SS,GB	64031512-64031912	5.5	9.6	110.	5.8	11.7	51.	9.2	13.5	155.
395	SS,GB	77020512-77021012	5.4	9.9	190.	7.8	11.5	151.	9.8	15.0	70.
309	SS,GB	73102600-73102912	5.3	10.7	269.	6.4	10.5	153.	10.8	15.0	65.
408	GB	78030100-78030500	5.3	9.4	144.	5.8	9.5	158.	11.5	13.8	115.
226	SS,GB	70012000-70012400	5.3	9.5	161.	6.1	10.1	150.	9.8	14.3	130.
265	SS,GB	72032612-72033100	5.1	10.4	207.	7.0	11.3	223.	4.7	13.6	13.
493	SS	83102400-83102800	4.9	9.8	213.	7.7	11.7	242.	5.7	13.2	2.
237	SS,GB	71011518-71011918	4.9	9.5	208.	5.9	9.9	132.	12.0	15.7	57.
515	SS,GB	85012512-85013012	4.7	9.4	135.	6.4	11.5	94.	11.4	15.4	64.
474	SS,GB	82021200-82021600	4.7	8.6	156.	7.6	10.7	112.	13.4	16.8	44.
40	SS,GB	59020612-59021012	4.3	9.3	94.	5.7	9.8	131.	9.3	13.4	84.
434	SS,GB	80021000-80021400	4.1	8.4	179.	7.3	10.9	196.	8.4	11.8	118.
NEW	SS	88030700-88031012	4.0	9.2	163.	6.6	10.0	172.	7.3	11.9	324.
499	GB	83121900-83122400	3.8	9.2	159.	8.1	13.2	156.	13.3	16.4	166.
394	GB	77011900-77012300	3.8	8.6	125.	5.9	10.8	94.	11.0	15.8	52.
121	GB	63111400-63111818	3.6	9.1	112.	5.4	10.5	135.	10.3	14.5	64.
317	GB	74010200-74010700	3.0	8.2	159.	4.3	9.6	140.	9.6	13.6	130.

List of 68 Storms Sorted by H_s - Scotian Shelf

		STORM	GRID PT 3498			GRID PT 3590			GRID PT 3744		
MCL#	REGION	START END	Hs (m)	Tp (s)	VMD (to)	Hs (m)	Tp (s)	VMD (to)	Hs (m)	Tp (s)	VMD (to)
241	SS	71030300-71030700	11.0	15.2	72.	10.5	16.9	61.	7.4	12.2	158.
189	SS,GB	67022100-67022500	10.1	13.3	90.	10.3	14.7	56.	12.6	16.8	49.
377	SS,GB	76031600-76032000	8.7	12.3	96.	10.2	14.5	65.	12.4	17.2	65.
147	SS	64113000-64120312	8.6	11.9	98.	10.0	14.4	47.	6.2	13.6	62.
235	SS,GB	70122600-70123000	6.8	10.7	126.	9.9	14.7	40.	7.9	15.7	47.
495	SS,GB	83112400-83113012	8.4	12.7	84.	9.7	14.6	66.	10.2	14.6	155.
464	SS,GB	81121500-81121912	8.3	13.1	66.	9.6	14.6	62.	9.4	15.6	69.
124	SS,GB	63121900-63122118	7.6	11.6	149.	9.4	13.3	74.	9.1	15.5	56.
453	SS	81031512-81032000	8.0	11.8	92.	9.3	14.6	36.	8.4	14.1	59.
467	SS,GB	82011300-82011900	7.6	11.0	102.	9.1	13.4	58.	12.6	17.2	58.
70	SS,GB	61011912-61012312	7.0	11.9	306.	8.9	14.9	78.	11.1	16.6	54.
451	SS	81030500-81031000	7.0	13.1	213.	8.9	13.9	230.	8.7	13.7	234.
132	SS,GB	64020800-64021018	6.1	11.0	94.	8.8	12.3	69.	9.3	14.6	63.
502	SS	84012912-84020312	7.3	11.6	59.	8.6	13.5	57.	6.3	12.2	70.
512	SS,GB	85010400-85010900	6.3	10.6	143.	8.6	12.5	93.	9.0	15.3	64.
282	SS,GB	72121512-72121912	7.5	11.7	114.	8.6	13.5	84.	8.8	15.1	70.
310	SS	73110100-73110512	7.9	12.0	99.	8.6	13.4	70.	7.6	14.8	65.
465	SS,GB	81122912-82010300	8.0	11.9	151.	8.6	12.1	146.	10.2	14.7	187.
200	SS,GB	68010418-68010800	6.8	10.4	143.	8.4	12.3	97.	10.1	15.3	68.
329	SS,GB	74031012-74031412	6.1	10.5	148.	8.4	11.6	158.	10.0	14.6	37.
404	SS	78010812-78011212	9.1	13.8	46.	8.4	13.8	38.	5.5	13.8	55.
499	GB	83121900-83122400	3.8	9.2	159.	8.1	13.2	156.	13.3	16.4	166.
325	SS,GB	74020400-74020800	6.9	10.8	169.	8.1	10.7	94.	7.0	10.9	114.
326	SS	74021612-74022000	6.7	10.5	104.	8.1	12.8	6.	6.5	12.6	21.
442	SS,GB	80111812-80112212	7.3	11.2	153.	8.0	11.2	132.	9.5	12.3	134.
195	SS	67042700-67050200	8.9	12.3	216.	8.0	12.1	289.	3.1	13.0	6.
172	SS,GB	66012612-66013012	8.9	12.2	102.	7.8	14.5	81.	9.6	12.5	304.
395	SS,GB	77020512-77021012	5.4	9.9	190.	7.8	11.5	151.	9.8	15.0	70.
493	SS	83102400-83102800	4.9	9.8	213.	7.7	11.7	242.	5.7	13.2	2.
260	SS,GB	72021812-72022200	7.5	13.5	71.	7.7	13.3	19.	7.2	13.1	15.
386	SS	76111812-76112300	5.6	10.4	116.	7.7	11.4	98.	7.4	11.9	324.
303	SS,EB	73032112-73032500	8.2	12.7	236.	7.7	11.9	251.	4.8	10.7	288.
474	SS,GB	82021200-82021600	4.7	8.6	156.	7.6	10.7	112.	13.4	16.8	44.
169	SS,GB	66010812-66011212	6.6	10.7	163.	7.6	11.8	168.	8.8	12.4	171.
433	SS,GB	80020612-80021012	7.6	11.3	209.	7.6	11.7	225.	8.1	12.9	208.
506	SS	84032812-84040112	8.2	13.1	201.	7.5	11.8	256.	6.8	11.0	98.
54	SS,GB	60010900-60011300	6.1	10.5	170.	7.5	12.2	163.	8.8	12.2	116.
223	SS	69122600-69123012	7.0	11.9	80.	7.5	12.0	330.	6.4	11.2	143.
NEW	EB	80011412-80011812	8.3	13.3	248.	7.4	12.0	271.	3.2	8.2	189.
434	SS,GB	80021000-80021400	4.1	8.4	179.	7.3	10.9	196.	8.4	11.8	118.
384	SS,GB	76110512-76111000	5.9	10.7	163.	7.3	12.3	83.	7.0	13.7	66.
215	SS	69020900-69021218	6.7	11.5	332.	7.2	11.8	329.	5.6	11.3	345.
102	SS	62111412-62111912	8.1	11.9	198.	7.2	11.4	278.	6.3	12.5	13.
526	GB	86010212-86010612	6.3	10.6	126.	7.2	11.0	61.	9.2	15.1	61.
129	SS,GB	64011212-64011718	7.3	11.7	178.	7.0	10.8	157.	10.9	14.3	95.
265	SS,GB	72032612-72033100	5.1	10.4	207.	7.0	11.3	223.	4.7	13.6	13.
174	SS,GB	66021318-66021812	6.3	10.8	60.	6.9	12.6	74.	12.0	15.1	138.
85	SS,GB	61121412-61121912	5.8	10.4	155.	6.8	11.0	153.	10.3	13.5	111.
443	SS	80112106-80112418	7.0	10.7	170.	6.8	11.0	229.	6.0	10.9	273.
523	GB	85121512-85122112	5.7	10.4	115.	6.7	11.2	87.	9.9	13.6	86.
421	GB	79020300-79020712	7.1	11.4	116.	6.7	11.8	102.	6.1	12.4	167.
NEW	SS	88030700-88031012	4.0	9.2	163.	6.6	10.0	172.	7.3	11.9	324.
463	SS,EB	81120412-81120812	6.9	10.8	109.	6.5	12.8	358.	4.1	14.5	30.
515	SS,GB	85012512-85013012	4.7	9.4	135.	6.4	11.5	94.	11.4	15.4	64.
309	SS,GB	73102600-73102912	5.3	10.7	269.	6.4	10.5	153.	10.8	15.0	65.
487	SS,GB	83021000-83021500	6.4	10.4	285.	6.3	10.1	142.	8.8	11.9	109.
95	SS	62030600-62030912	8.2	12.0	249.	6.2	11.8	247.	5.2	10.8	191.
226	SS,GB	70012000-70012400	5.3	9.5	161.	6.1	10.1	150.	9.8	14.3	130.
394	GB	77011900-77012300	3.8	8.6	125.	5.9	10.8	94.	11.0	15.8	52.
106	SS	62123000-63010218	6.3	10.6	121.	5.9	10.5	328.	6.4	11.8	304.
237	SS,GB	71011518-71011918	4.9	9.5	208.	5.9	9.9	132.	12.0	15.7	57.
408	GB	78030100-78030500	5.3	9.4	144.	5.8	9.5	158.	11.5	13.8	115.
140	SS,GB	64031512-64031912	5.5	9.6	110.	5.8	11.7	51.	9.2	13.5	155.
40	SS,GB	59020612-59021012	4.3	9.3	94.	5.7	9.8	131.	9.3	13.4	84.
121	GB	63111400-63111818	3.6	9.1	112.	5.4	10.5	135.	10.3	14.5	64.
488	SS,GB	83021506-83021900	5.8	11.1	258.	5.3	10.1	205.	10.3	13.2	210.
151	GB	65012112-65012512	5.6	9.4	207.	4.6	9.2	316.	7.4	12.9	136.
317	GB	74010200-74010700	3.0	8.2	159.	4.3	9.6	140.	9.6	13.6	130.

List of 68 Storms Sorted by H_s - Grand Banks

MCL#	REGION	STORM	GRID PT 3498			GRID PT 3590			GRID PT 3744		
		START END	Hs (m)	Tp (s)	VMD (to)	Hs (m)	Tp (s)	VMD (to)	Hs (m)	Tp (s)	VMD (to)
474	SS,GB	82021200-82021600	4.7	8.6	156.	7.6	10.7	112.	13.4	16.8	44.
499	GB	83121900-83122400	3.8	9.2	159.	8.1	13.2	156.	13.3	16.4	166.
189	SS,GB	67022100-67022500	10.1	13.3	90.	10.3	14.7	56.	12.6	16.8	49.
467	SS,GB	82011300-82011900	7.6	11.0	102.	9.1	13.4	58.	12.6	17.2	58.
377	SS,GB	76031600-76032000	8.7	12.3	96.	10.2	14.5	65.	12.4	17.2	65.
237	SS,GB	71011518-71011918	4.9	9.5	208.	5.9	9.9	132.	12.0	15.7	57.
174	SS,GB	66021318-66021812	6.3	10.8	60.	6.9	12.6	74.	12.0	15.1	138.
408	GB	78030100-78030500	5.3	9.4	144.	5.8	9.5	158.	11.5	13.8	115.
515	SS,GB	85012512-85013012	4.7	9.4	135.	6.4	11.5	94.	11.4	15.4	64.
70	SS,GB	61011912-61012312	7.0	11.9	306.	8.9	14.9	78.	11.1	16.6	54.
394	GB	77011900-77012300	3.8	8.6	125.	5.9	10.8	94.	11.0	15.8	52.
129	SS,GB	64011212-64011718	7.3	11.7	178.	7.0	10.8	157.	10.9	14.3	95.
309	SS,GB	73102600-73102912	5.3	10.7	269.	6.4	10.5	153.	10.8	15.0	65.
121	GB	63111400-63111818	3.6	9.1	112.	5.4	10.5	135.	10.3	14.5	64.
85	SS,GB	61121412-61121912	5.8	10.4	155.	6.8	11.0	153.	10.3	13.5	111.
488	SS,GB	83021506-83021900	5.8	11.1	258.	5.3	10.1	205.	10.3	13.2	210.
465	SS,GB	81122912-82010300	8.0	11.9	151.	8.6	12.1	146.	10.2	14.7	187.
495	SS,GB	83112400-83113012	8.4	12.7	84.	9.7	14.6	66.	10.2	14.6	155.
200	SS,GB	68010418-68010800	6.8	10.4	143.	8.4	12.3	97.	10.1	15.3	68.
329	SS,GB	74031012-74031412	6.1	10.5	148.	8.4	11.6	158.	10.0	14.6	37.
523	GB	85121512-85122112	5.7	10.4	115.	6.7	11.2	87.	9.9	13.6	86.
395	SS,GB	77020512-77021012	5.4	9.9	190.	7.8	11.5	151.	9.8	15.0	70.
226	SS,GB	70012000-70012400	5.3	9.5	161.	6.1	10.1	150.	9.8	14.3	130.
317	GB	74010200-74010700	3.0	8.2	159.	4.3	9.6	140.	9.6	13.6	130.
172	SS,GB	66012612-66013012	8.9	12.2	102.	7.8	14.5	81.	9.6	12.5	304.
442	SS,GB	80111812-80112212	7.3	11.2	153.	8.0	11.2	132.	9.5	12.3	134.
464	SS,GB	81121500-81121912	8.3	13.1	66.	9.6	14.6	62.	9.4	15.6	69.
132	SS,GB	64020800-64021018	6.1	11.0	94.	8.8	12.3	69.	9.3	14.6	63.
40	SS,GB	59020612-59021012	4.3	9.3	94.	5.7	9.8	131.	9.3	13.4	84.
526	GB	86010212-86010612	6.3	10.6	126.	7.2	11.0	61.	9.2	15.1	61.
140	SS,GB	64031512-64031912	5.5	9.6	110.	5.8	11.7	51.	9.2	13.5	155.
124	SS,GB	63121900-63122118	7.6	11.6	149.	9.4	13.3	74.	9.1	15.5	56.
512	SS,GB	85010400-85010900	6.3	10.6	143.	8.6	12.5	93.	9.0	15.3	64.
487	SS,GB	83021000-83021500	6.4	10.4	285.	6.3	10.1	142.	8.8	11.9	109.
169	SS,GB	66010812-66011212	6.6	10.7	163.	7.6	11.8	168.	8.8	12.4	171.
54	SS,GB	60010900-60011300	6.1	10.5	170.	7.5	12.2	163.	8.8	12.2	116.
282	SS,GB	72121512-72121912	7.5	11.7	114.	8.6	13.5	84.	8.8	15.1	70.
451	SS	81030500-81031000	7.0	13.1	213.	8.9	13.9	230.	8.7	13.7	234.
434	SS,GB	80021000-80021400	4.1	8.4	179.	7.3	10.9	196.	8.4	11.8	118.
453	SS	81031512-81032000	8.0	11.8	92.	9.3	14.6	36.	8.4	14.1	59.
433	SS,GB	80020612-80021012	7.6	11.3	209.	7.6	11.7	225.	8.1	12.9	208.
235	SS,GB	70122600-70123000	6.8	10.7	126.	9.9	14.7	40.	7.9	15.7	47.
310	SS	73110100-73110512	7.9	12.0	99.	8.6	13.4	70.	7.6	14.8	65.
241	SS	71030300-71030700	11.0	15.2	72.	10.5	16.9	61.	7.4	12.2	158.
151	GB	65012112-65012512	5.6	9.4	207.	4.6	9.2	316.	7.4	12.9	136.
386	SS	76111812-76112300	5.6	10.4	116.	7.7	11.4	98.	7.4	11.9	324.
NEW	SS	88030700-88031012	4.0	9.2	163.	6.6	10.0	172.	7.3	11.9	324.
260	SS,GB	72021812-72022200	7.5	13.5	71.	7.7	13.3	19.	7.2	13.1	15.
384	SS,GB	76110512-76111000	5.9	10.7	163.	7.3	12.3	83.	7.0	13.7	66.
325	SS,GB	74020400-74020800	6.9	10.8	169.	8.1	10.7	94.	7.0	10.9	114.
506	SS	84032812-84040112	8.2	13.1	201.	7.5	11.8	256.	6.8	11.0	98.
326	SS	74021612-74022000	6.7	10.5	104.	8.1	12.8	6.	6.5	12.6	21.
106	SS	62123000-63010218	6.3	10.6	121.	5.9	10.5	328.	6.4	11.8	304.
223	SS	69122600-69123012	7.0	11.9	80.	7.5	12.0	330.	6.4	11.2	143.
502	SS	84012912-84020312	7.3	11.6	59.	8.6	13.5	57.	6.3	12.2	70.
102	SS	62111412-62111912	8.1	11.9	198.	7.2	11.4	278.	6.3	12.5	13.
147	SS	64113000-64120312	8.6	11.9	98.	10.0	14.4	47.	6.2	13.6	62.
421	GB	79020300-79020712	7.1	11.4	116.	6.7	11.8	102.	6.1	12.4	167.
443	SS	80112106-80112418	7.0	10.7	170.	6.8	11.0	229.	6.0	10.9	273.
493	SS	83102400-83102800	4.9	9.8	213.	7.7	11.7	242.	5.7	13.2	2.
215	SS	69020900-69021218	6.7	11.5	332.	7.2	11.8	329.	5.6	11.3	345.
404	SS	78010812-78011212	9.1	13.8	46.	8.4	13.8	38.	5.5	13.8	55.
95	SS	62030600-62030912	8.2	12.0	249.	6.2	11.8	247.	5.2	10.8	191.
303	SS,EB	73032112-73032500	8.2	12.7	236.	7.7	11.9	251.	4.8	10.7	288.
265	SS,GB	72032612-72033100	5.1	10.4	207.	7.0	11.3	223.	4.7	13.6	13.
463	SS,EB	81120412-81120812	6.9	10.8	109.	6.5	12.8	358.	4.1	14.5	30.
NEW	EB	80011412-80011812	8.3	13.3	248.	7.4	12.0	271.	3.2	8.2	189.
195	SS	67042700-67050200	8.9	12.3	216.	8.0	12.1	289.	3.1	13.0	6.

Georges Bank

Grid point 3468 – 41.25 N, 67.50 W

GUMBEL – Method of Moments

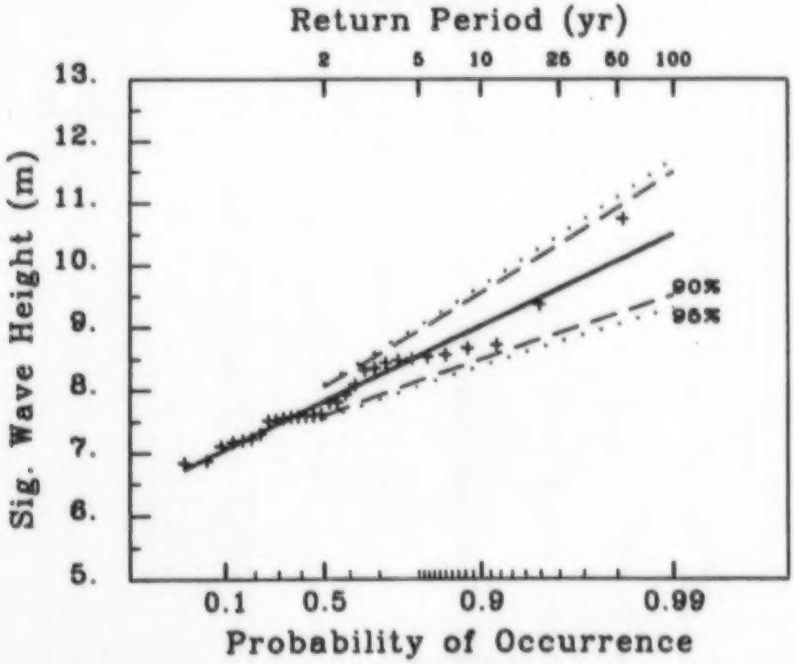
30 storms
Wave height threshold = 6.84 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	7.8	8.1	11.9	14.5	8.1
5	8.5	8.9	12.6	15.9	8.8
10	9.0	9.5	13.0	16.8	9.3
25	9.6	10.3	13.5	17.9	10.0
50	10.1	10.9	13.9	18.7	10.4
100	10.5	11.5	14.2	19.5	10.9

Tp, Hmax, and Hc were calculated using

$$Tp = 3.464\ Hs^{0.600}$$
$$Hmax = 1.858\ Hs$$
$$Hc = 1.035\ Hs$$

Correlation = 0.98



Georges Bank

Grid point 3526 - 42.50 N, 67.50 W

GUMBEL - Method of Moments

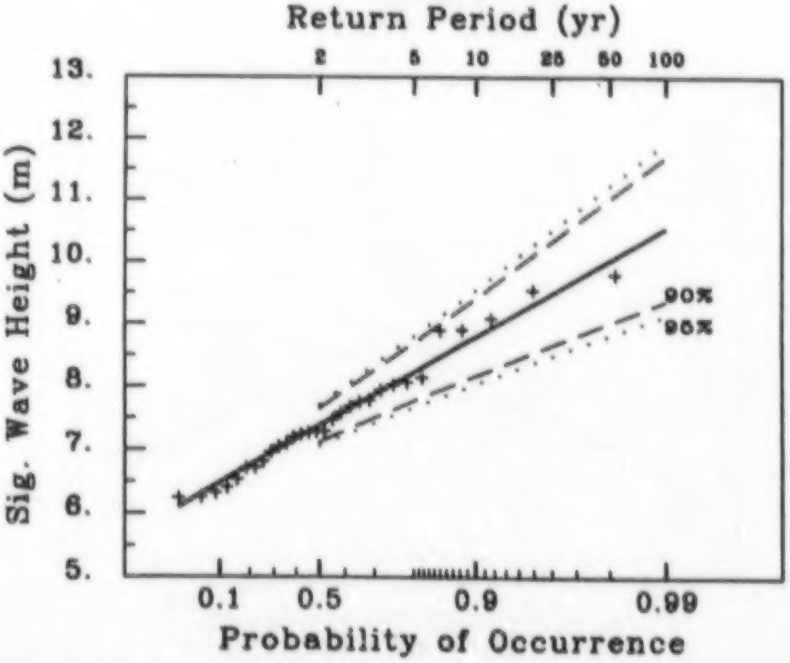
30 storms
Wave height threshold = 6.24 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	7.4	7.7	11.6	13.8	7.7
5	8.2	8.7	12.2	15.4	8.6
10	8.8	9.4	12.7	16.5	9.2
25	9.5	10.3	13.2	17.8	9.9
50	10.0	11.0	13.5	18.8	10.5
100	10.5	11.7	13.9	19.8	11.0

Tp, Hmax, and Hc were calculated using

$$Tp = 4.142\ Hs^{0.514}$$
$$Hmax = 1.876\ Hs$$
$$Hc = 1.046\ Hs$$

Correlation = 0.99



Scotian Shelf

Grid point 3528 – 42.50 N, 65.00 W

GUMBEL – Method of Moments

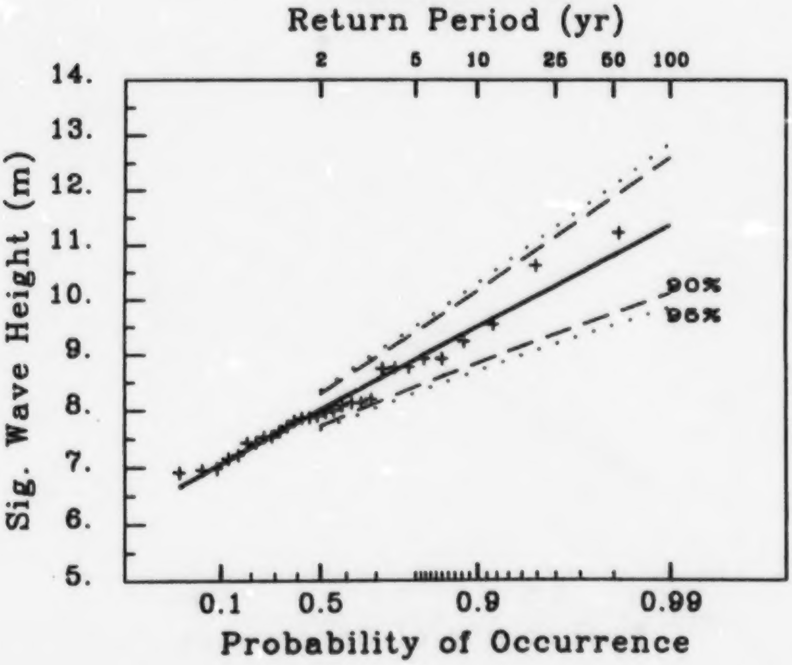
30 storms
Wave height threshold = 6.91 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.0	8.3	12.2	15.0	8.3
5	8.9	9.4	13.0	16.6	9.3
10	9.5	10.2	13.6	17.8	9.9
25	10.3	11.1	14.2	19.2	10.7
50	10.8	11.9	14.7	20.2	11.3
100	11.4	12.6	15.2	21.2	11.8

Tp, Hmax, and Hc were calculated using

$$Tp = 3.337\ Hs^{0.623}$$
$$Hmax = 1.868\ Hs$$
$$Hc = 1.041\ Hs$$

Correlation = 0.99



Scotian Shelf

Grid point 3530 - 42.50 N, 62.50 W

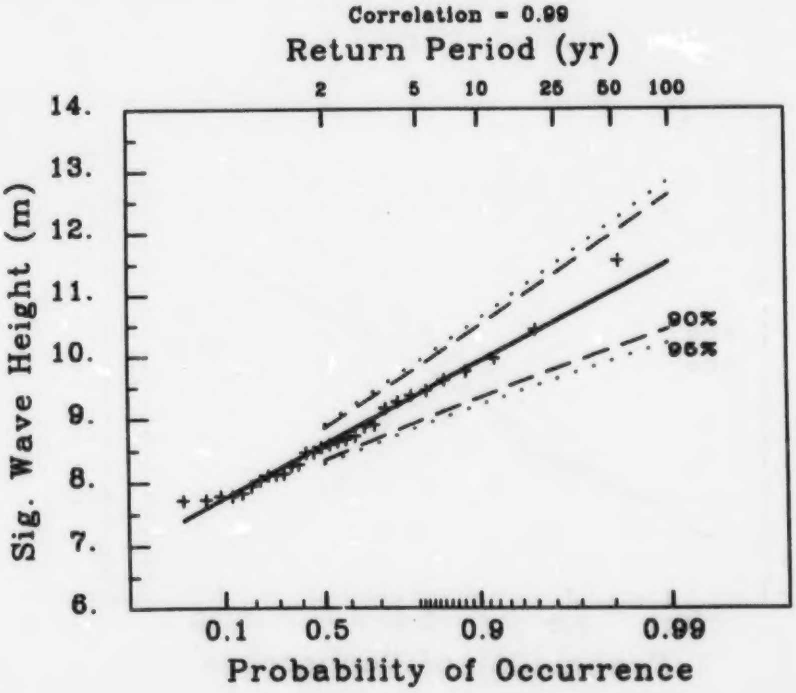
GUMBEL - Method of Moments

30 storms
Wave height threshold = 7.72 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.6	8.8	13.0	16.0	8.9
5	9.4	9.8	13.7	17.4	9.7
10	9.9	10.5	14.2	18.4	10.2
25	10.6	11.3	14.9	19.6	10.9
50	11.1	12.0	15.3	20.5	11.4
100	11.5	12.6	15.6	21.4	11.9

Tp, Hmax, and Hc were calculated using

$$Tp = 3.050\ Hs^{0.672}$$
$$Hmax = 1.857\ Hs$$
$$Hc = 1.035\ Hs$$



Scotian Shelf

Grid point 3589 - 43.75 N, 61.25 W

GUMBEL - Method of Moments

30 storms

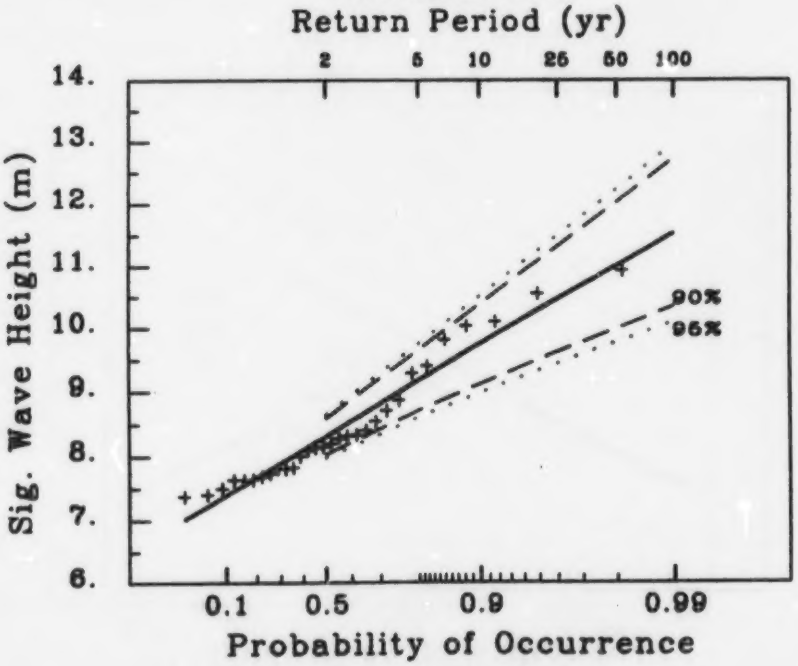
Wave height threshold = 7.38 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.3	8.6	12.9	15.5	8.6
5	9.2	9.6	13.9	17.1	9.5
10	9.7	10.4	14.5	18.1	10.1
25	10.5	11.3	15.2	19.5	10.9
50	11.0	12.0	15.8	20.5	11.4
100	11.5	12.7	16.3	21.5	12.0

Tp, Hmax, and Hc were calculated using

$$Tp = 2.866\ Hs^{0.710}$$
$$Hmax = 1.860\ Hs$$
$$Hc = 1.037\ Hs$$

Correlation = 0.98



Grand Banks

Grid point 3598 – 43.75 N, 50.00 W

GUMBEL – Method of Moments

30 storms

Wave height threshold = 9.12 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.3	10.6	14.9	19.2	10.7
5	11.3	11.8	15.4	21.1	11.8
10	12.0	12.7	15.7	22.4	12.5
25	12.8	13.8	16.2	24.0	13.3
50	13.4	14.6	16.5	25.1	14.0
100	14.0	15.4	16.8	26.3	14.6

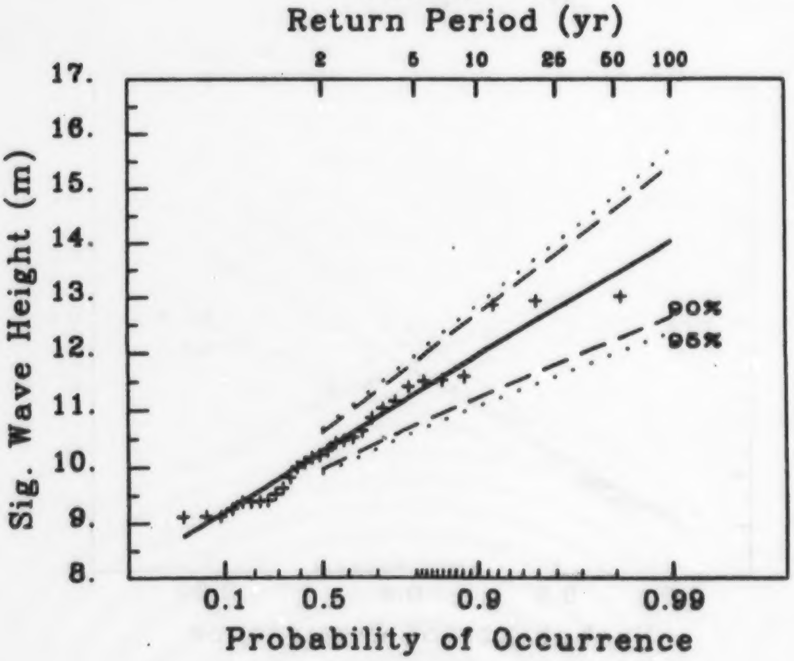
Tp, Hmax, and Hc were calculated using

$$Tp = 6.036\ Hs^{0.386}$$

$$Hmax = 1.873\ Hs$$

$$Hc = 1.043\ Hs$$

Correlation = 0.98



Scotian Shelf

Grid point 3617 - 44.38 N, 62.50 W

GUMBEL - Method of Moments

30 storms

Wave height threshold = 6.25 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	7.4	7.7	12.4	13.8	7.7
5	8.5	9.0	13.4	15.8	8.8
10	9.1	9.9	14.0	17.1	9.5
25	10.0	11.1	14.8	18.7	10.4
50	10.7	11.9	15.3	19.9	11.1
100	11.3	12.7	15.9	21.1	11.8

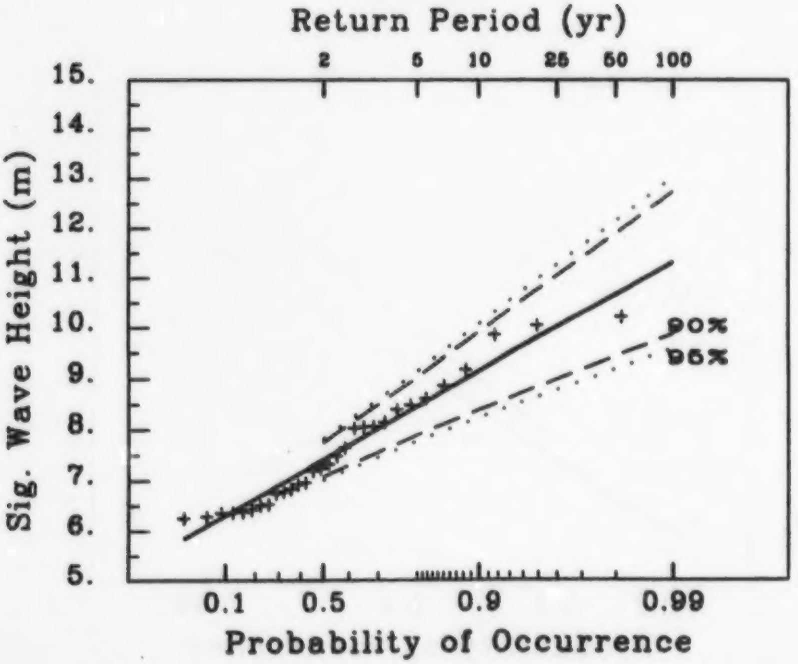
Tp, Hmax, and Hc were calculated using

$$Tp = 3.799\ Hs^{0.589}$$

$$Hmax = 1.866\ Hs$$

$$Hc = 1.042\ Hs$$

Correlation = 0.98



Scotian Shelf

Grid point 3620 – 44.38 N, 58.75 W

GUMBEL – Method of Moments

30 storms

Wave height threshold = 7.79 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.7	9.0	13.4	16.3	9.1
5	9.4	9.8	14.2	17.6	9.8
10	9.9	10.4	14.7	18.4	10.3
25	10.4	11.1	15.4	19.5	10.8
50	10.8	11.6	15.8	20.2	11.3
100	11.3	12.2	16.3	21.0	11.7

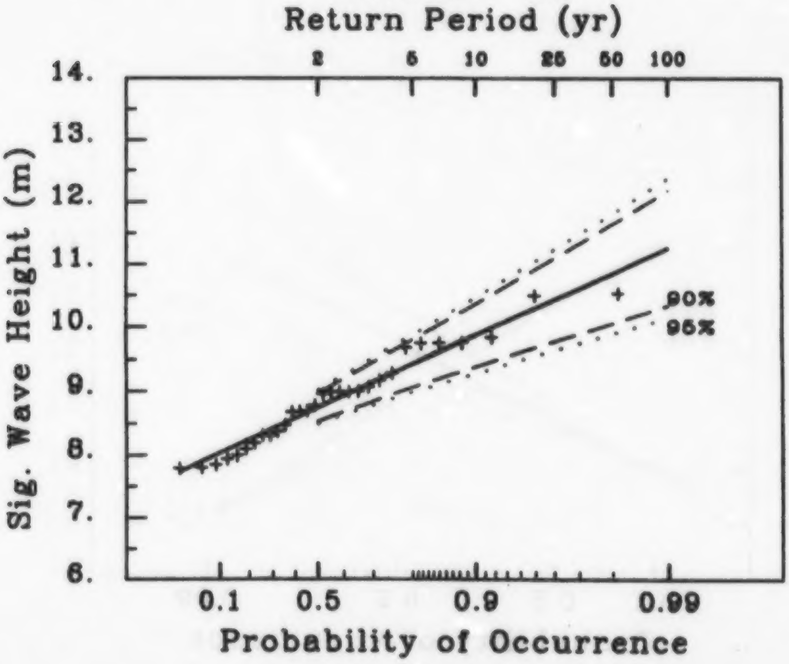
Tp, Hmax, and Hc were calculated using

$$Tp = 2.503\ Hs^{0.774}$$

$$Hmax = 1.867\ Hs$$

$$Hc = 1.040\ Hs$$

Correlation = 0.98



Grand Banks

Grid point 3654 - 45.00 N, 52.50 W

GUMBEL - Method of Moments

30 storms

Wave height threshold = 8.93 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	9.9	10.1	14.3	18.4	10.3
5	10.6	11.1	14.8	19.9	11.1
10	11.2	11.8	15.1	20.9	11.6
25	11.8	12.6	15.4	22.2	12.3
50	12.3	13.3	15.7	23.1	12.9
100	12.8	13.9	15.9	24.0	13.4

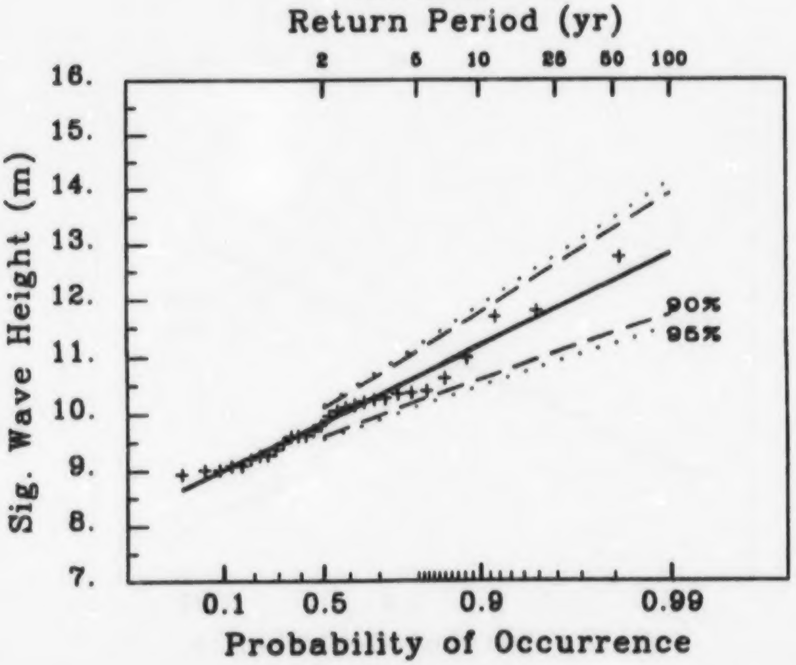
Tp, Hmax, and Hc were calculated using

$$Tp = 5.667\ Hs^{0.406}$$

$$Hmax = 1.872\ Hs$$

$$Hc = 1.043\ Hs$$

Correlation = 0.99



Grand Banks

Grid point 3656 - 45.00 N, 50.00 W

GUMBEL - Method of Moments

30 storms

Wave height threshold = 9.13 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.3	10.7	14.6	19.4	10.8
5	11.3	11.9	15.3	21.2	11.8
10	12.0	12.7	15.7	22.5	12.5
25	12.8	13.8	16.2	24.1	13.4
50	13.5	14.7	16.6	25.2	14.0
100	14.1	15.5	17.0	26.4	14.7

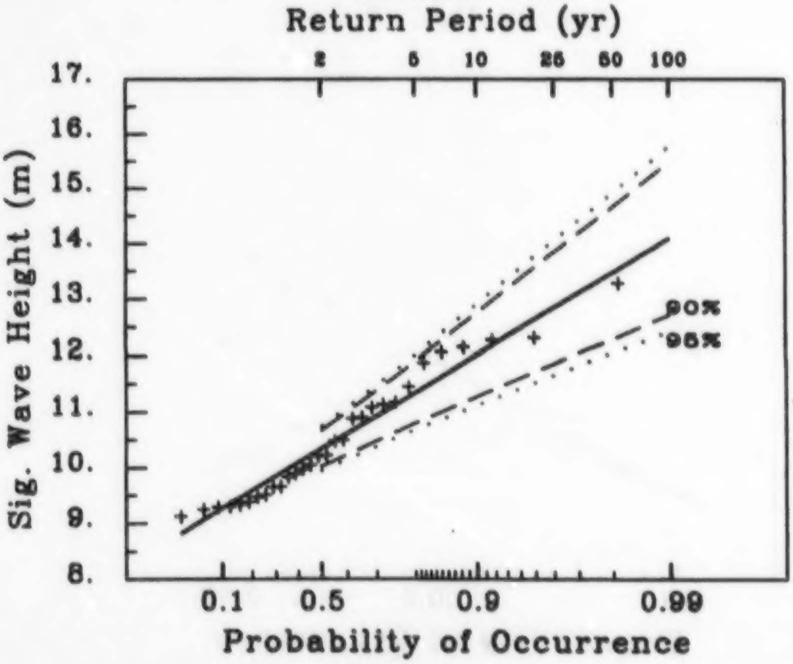
Tp, Hmax, and Hc were calculated using

$$Tp = 4.530\ Hs^{0.500}$$

$$Hmax = 1.873\ Hs$$

$$Hc = 1.042\ Hs$$

Correlation = 0.98



Grand Banks

Grid point 3708 - 46.25 N, 57.50 W

GUMBEL - Method of Moments

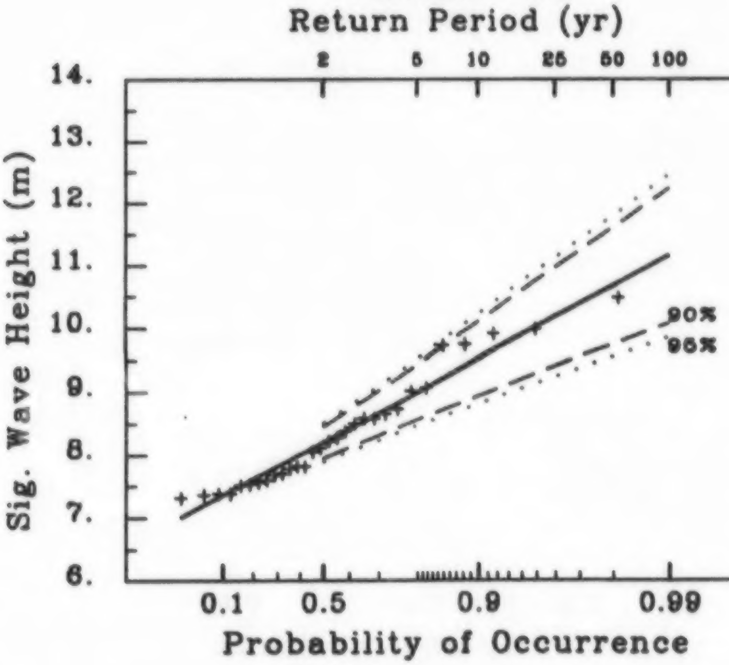
30 storms
Wave height threshold = 7.32 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.2	8.5	13.0	15.5	8.7
5	9.0	9.4	13.8	17.0	9.5
10	9.5	10.1	14.3	18.0	10.0
25	10.2	11.0	15.0	19.2	10.7
50	10.7	11.6	15.4	20.2	11.3
100	11.1	12.2	15.9	21.1	11.8

Tp, Hmax, and Hc were calculated using

$$Tp = 3.217\ Hs^{0.663}$$
$$Hmax = 1.892\ Hs$$
$$Hc = 1.055\ Hs$$

Correlation = 0.98



Grand Banks

Grid point 3710 - 46.25 N, 55.00 W

GUMBEL - Method of Moments

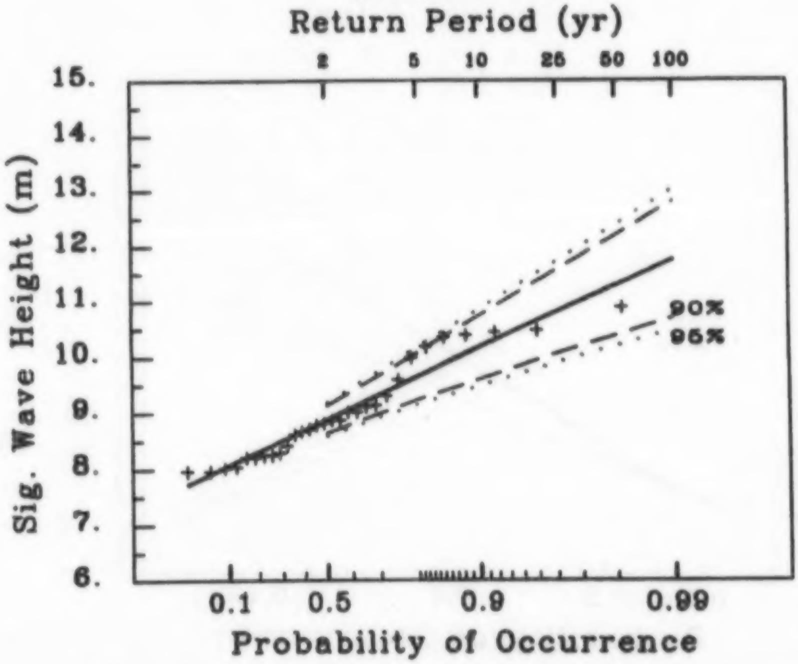
30 storms
Wave height threshold = 7.96 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	8.9	9.1	13.7	16.7	9.3
5	9.6	10.1	14.3	18.1	10.1
10	10.2	10.7	14.7	19.1	10.6
25	10.8	11.6	15.3	20.3	11.3
50	11.3	12.2	15.6	21.2	11.8
100	11.7	12.8	16.0	22.1	12.3

Tp, Hmax, and Hc were calculated using

$$Tp = 3.920\ Hs^{0.571}$$
$$Hmax = 1.878\ Hs$$
$$Hc = 1.047\ Hs$$

Correlation = 0.97



Grand Banks

Grid point 3713 - 46.25 N, 51.25 W

GUMBEL - Method of Moments

30 storms

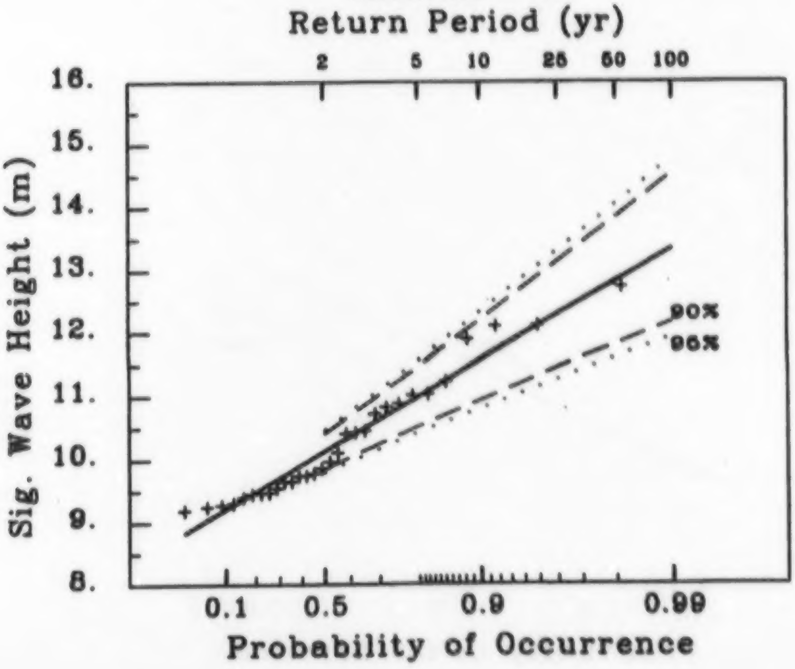
Wave height threshold = 9.20 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.1	10.4	14.4	19.0	10.6
5	11.0	11.5	15.1	20.6	11.4
10	11.6	12.2	15.6	21.6	12.0
25	12.3	13.1	16.2	23.0	12.8
50	12.8	13.8	16.7	24.0	13.3
100	13.3	14.5	17.1	25.0	13.9

Tp, Hmax, and Hc were calculated using

$$Tp = 3.332\ Hs^{0.632}$$
$$Hmax = 1.873\ Hs$$
$$Hc = 1.042\ Hs$$

Correlation = 0.98



Grand Banks

Grid point 3714 - 46.25 N, 50.00 W

GUMBEL - Method of Moments

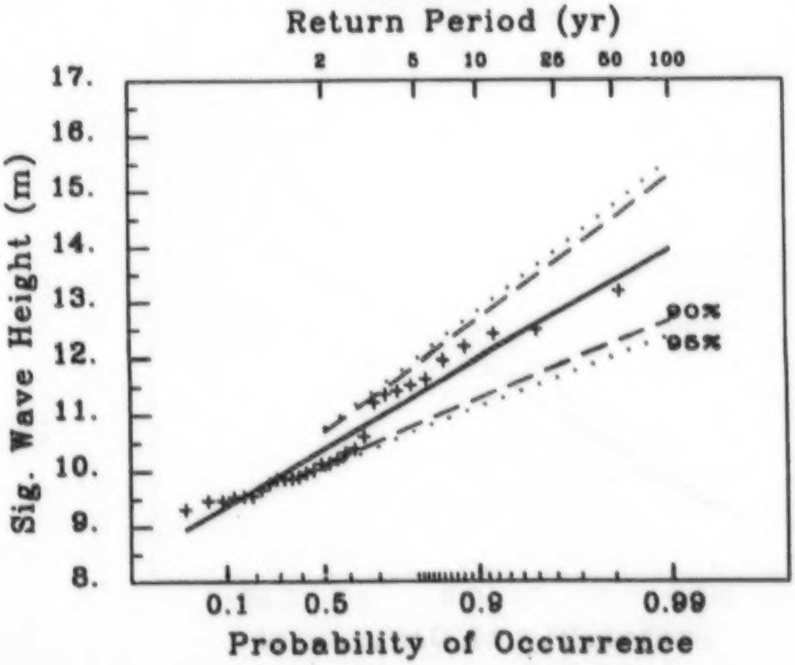
30 storms
Wave height threshold = 9.31 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.4	10.7	14.7	19.5	10.8
5	11.3	11.9	15.4	21.2	11.8
10	12.0	12.7	15.8	22.4	12.5
25	12.8	13.7	16.3	23.9	13.3
50	13.4	14.5	16.7	25.0	13.9
100	13.9	15.3	17.1	26.1	14.5

Tp, Hmax, and Hc were calculated using

$$Tp = 4.546\ Hs^{0.502}$$
$$Hmax = 1.874\ Hs$$
$$Hc = 1.042\ Hs$$

Correlation = 0.97



Grand Banks

Grid point 3715 – 46.25 N, 48.75 W

GUMBEL – Method of Moments

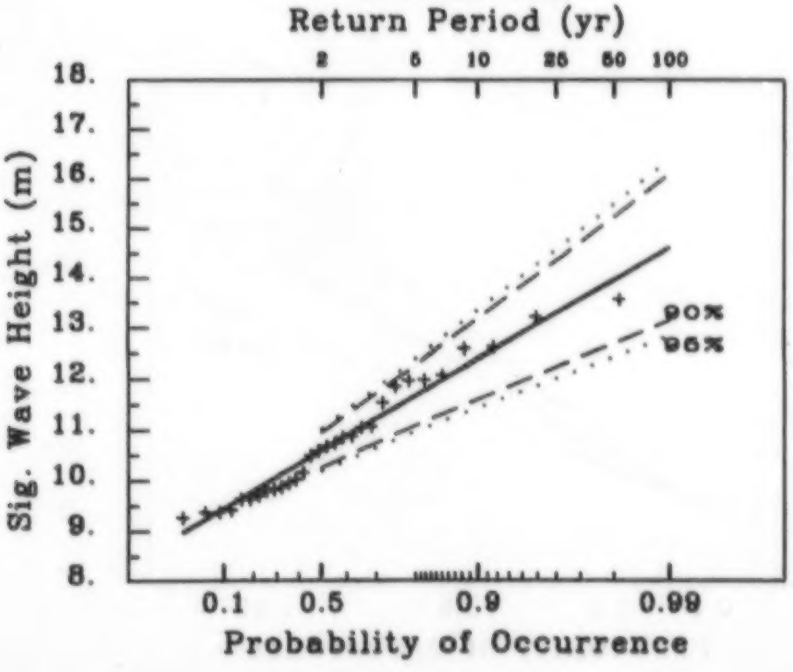
30 storms
Wave height threshold = 9.26 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.6	10.9	14.8	19.9	11.1
5	11.7	12.2	15.6	22.0	12.2
10	12.4	13.2	16.2	23.3	13.0
25	13.3	14.3	16.8	25.0	13.9
50	13.9	15.2	17.3	26.2	14.6
100	14.6	16.1	17.8	27.5	15.3

Tp, Hmax, and Hc were calculated using

$$Tp = 3.824\ Hs^{0.573}$$
$$Hmax = 1.882\ Hs$$
$$Hc = 1.047\ Hs$$

Correlation = 0.99



Grand Banks

Grid point 3716 - 46.25 N, 47.50 W

GUMBEL - Method of Moments

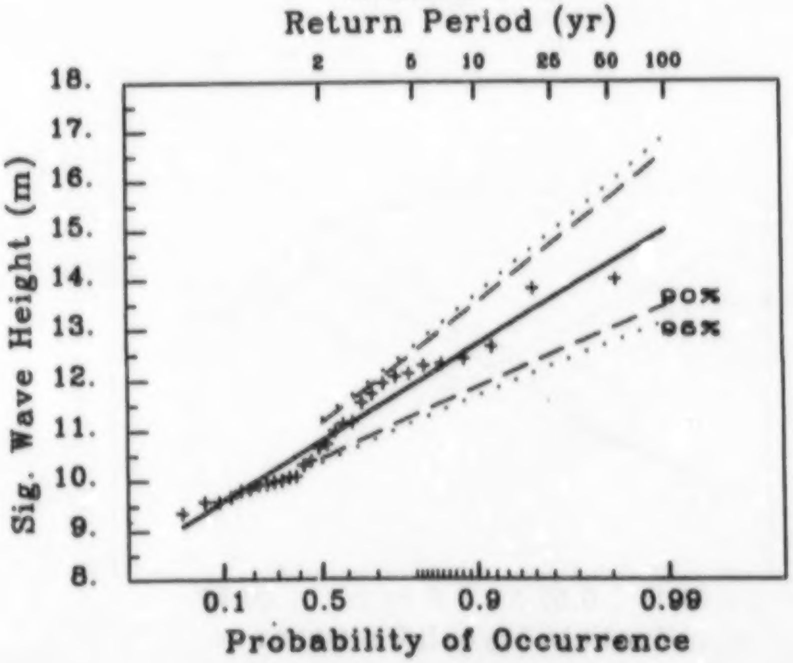
30 storms
Wave height threshold = 9.35 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.8	11.1	15.0	20.2	11.2
5	11.9	12.5	15.8	22.3	12.4
10	12.7	13.5	16.4	23.7	13.2
25	13.6	14.7	17.0	25.5	14.2
50	14.3	15.6	17.5	26.8	14.9
100	15.0	16.6	18.0	28.1	15.6

Tp, Hmax, and Hc were calculated using

$$Tp = 3.983\ Hs^{0.557}$$
$$Hmax = 1.872\ Hs$$
$$Hc = 1.041\ Hs$$

Correlation = 0.98



Grand Banks

Grid point 3771 - 47.50 N, 51.25 W

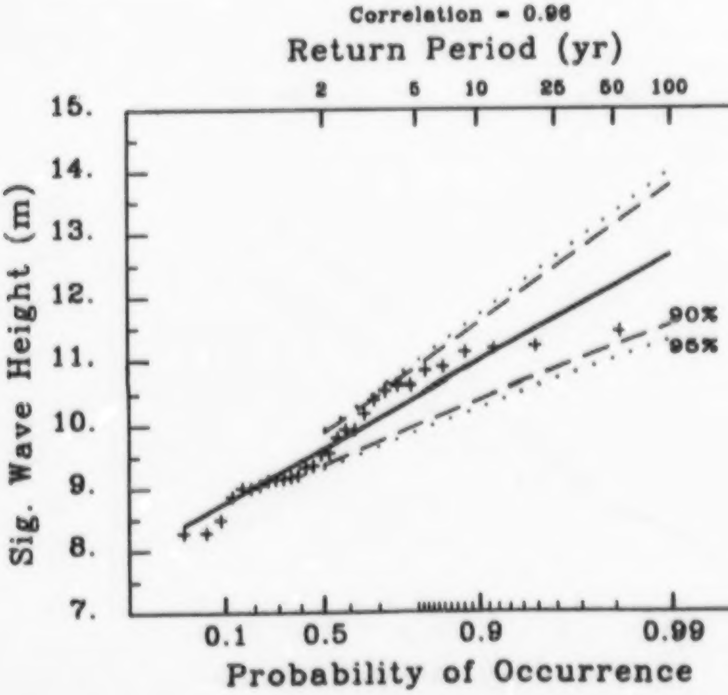
GUMBEL - Method of Moments

30 storms
Wave height threshold = 8.28 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	9.6	9.9	14.5	18.0	10.0
5	10.4	10.9	14.9	19.5	10.9
10	11.0	11.6	15.2	20.5	11.4
25	11.6	12.4	15.5	21.8	12.1
50	12.2	13.1	15.8	22.8	12.7
100	12.7	13.8	16.0	23.7	13.2

Tp, Hmax, and Hc were calculated using

$$Tp = 6.351\ Hs^{0.364}$$
$$Hmax = 1.874\ Hs$$
$$Hc = 1.042\ Hs$$



Grand Banks

Grid point 3772 - 47.50 N, 50.00 W

GUMBEL - Method of Moments

30 storms

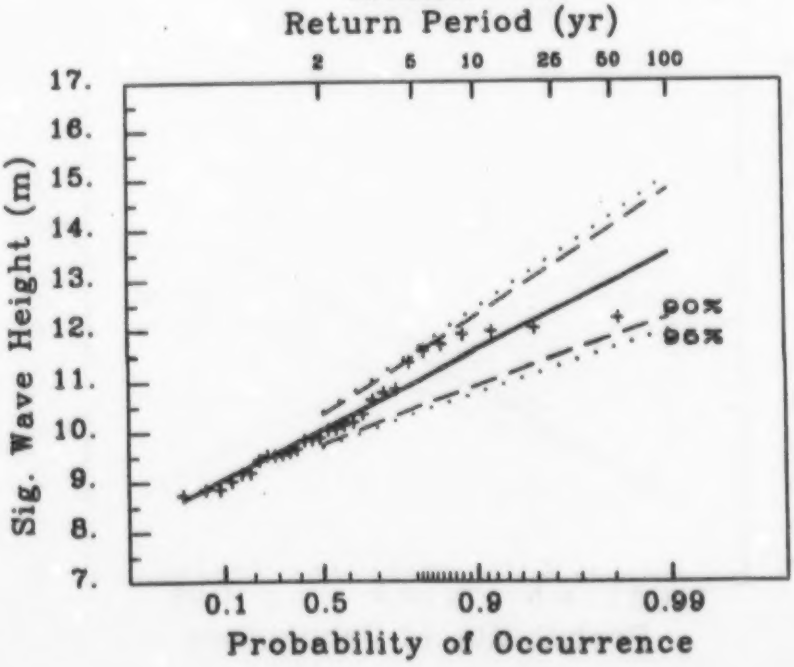
Wave height threshold = 8.73 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.0	10.3	14.4	18.7	10.4
5	11.0	11.5	15.3	20.5	11.4
10	11.6	12.3	15.9	21.6	12.0
25	12.4	13.3	16.6	23.1	12.8
50	12.9	14.0	17.1	24.2	13.4
100	13.5	14.8	17.6	25.2	14.0

Tp, Hmax, and Hc were calculated using

$$Tp = 3.118\ Hs^{0.664}$$
$$Hmax = 1.868\ Hs$$
$$Hc = 1.039\ Hs$$

Correlation = 0.97



Grand Banks

Grid point 3774 - 47.50 N, 47.50 W

GUMBEL - Method of Moments

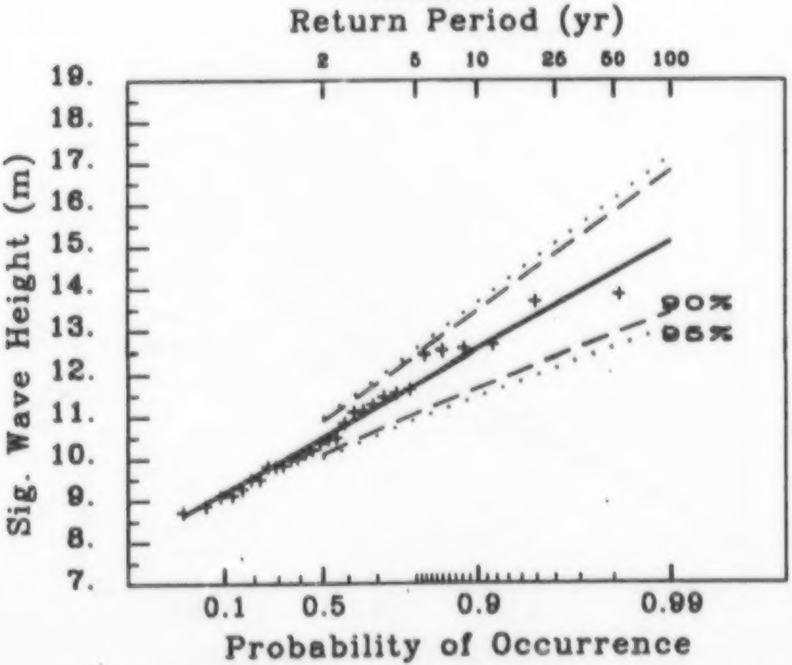
30 storms
Wave height threshold = 8.72 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	10.5	10.9	14.9	19.7	11.0
5	11.7	12.4	15.8	22.0	12.3
10	12.6	13.5	16.5	23.6	13.1
25	13.6	14.8	17.2	25.5	14.2
50	14.4	15.8	17.8	26.9	15.0
100	15.1	16.8	18.3	28.4	15.8

Tp, Hmax, and Hc were calculated using

$$Tp = 3.838\ Hs^{0.576}$$
$$Hmax = 1.876\ Hs$$
$$Hc = 1.044\ Hs$$

Correlation = 0.99



Grand Banks

Grid point 3829 – 48.75 N, 51.25 W

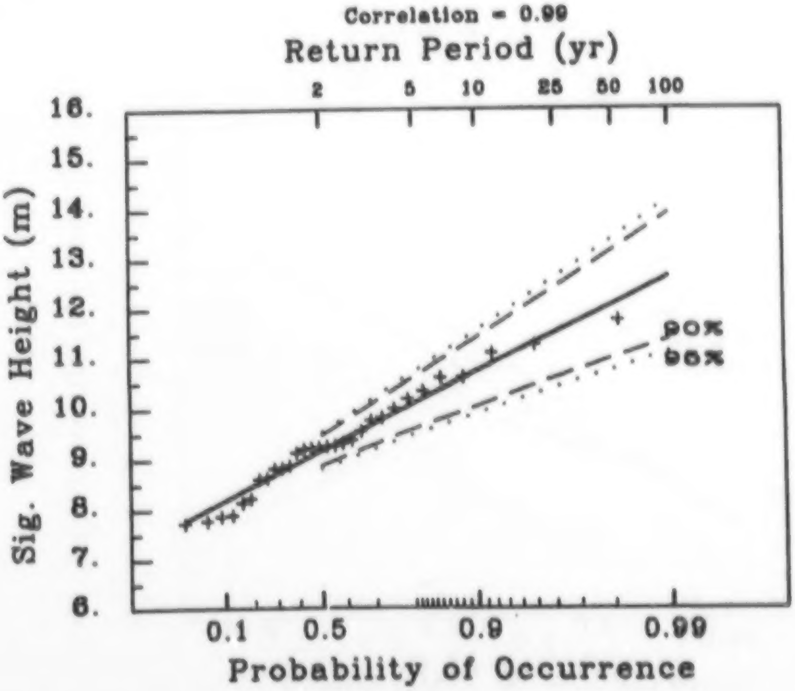
GUMBEL – Method of Moments

30 storms
Wave height threshold = 7.73 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	9.2	9.5	13.6	17.2	9.6
5	10.1	10.6	14.0	18.9	10.5
10	10.7	11.4	14.2	20.1	11.2
25	11.5	12.4	14.5	21.5	12.0
50	12.1	13.2	14.7	22.6	12.6
100	12.6	13.9	14.8	23.7	13.2

Tp, Hmax, and Hc were calculated using

$$Tp = 7.573\ Hs^{0.265}$$
$$Hmax = 1.876\ Hs$$
$$Hc = 1.043\ Hs$$



Grand Banks

Grid point 3831 - 48.75 N, 48.75 W

GUMBEL - Method of Moments

30 storms

Wave height threshold = 8.54 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	9.9	10.2	14.3	18.6	10.3
5	10.8	11.3	14.8	20.3	11.3
10	11.5	12.1	15.2	21.5	11.9
25	12.2	13.1	15.6	22.9	12.8
50	12.8	13.9	15.9	24.0	13.4
100	13.4	14.6	16.2	25.1	13.9

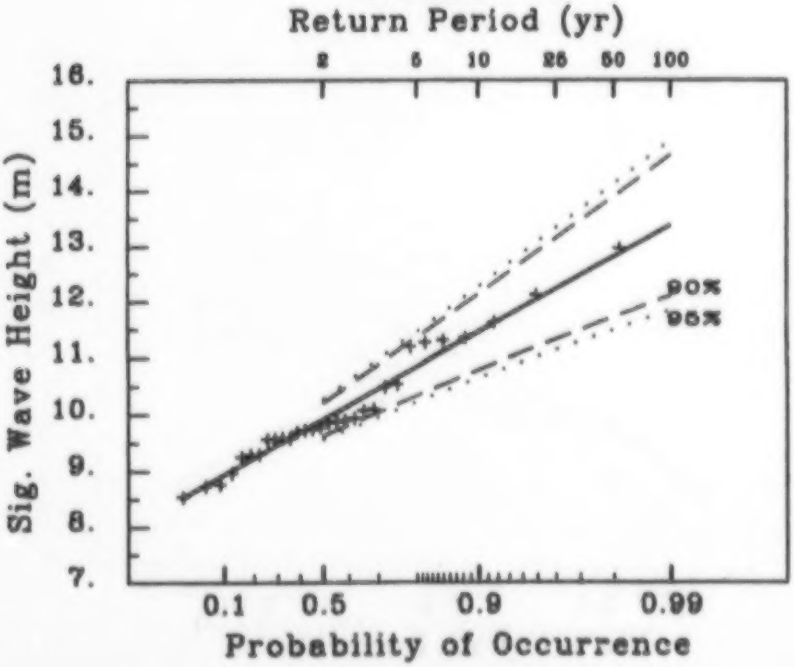
Tp, Hmax, and Hc were calculated using

$$Tp = 5.234\ Hs^{0.437}$$

$$Hmax = 1.877\ Hs$$

$$Hc = 1.043\ Hs$$

Correlation = 0.99



Grand Banks

Grid point 3888 - 50.00 N, 50.00 W

GUMBEL - Method of Moments

30 storms

Wave height threshold = 7.98 m

Return Period (yr)	Best Fit (m)	90% U.L. (m)	Tp (s)	Hmax (m)	Hc (m)
2	9.3	9.6	13.5	17.4	9.7
5	10.2	10.7	13.9	19.1	10.6
10	10.8	11.4	14.2	20.2	11.2
25	11.5	12.4	14.6	21.6	12.0
50	12.1	13.2	14.9	22.7	12.6
100	12.7	13.9	15.1	23.7	13.2

Tp, Hmax, and Hc were calculated using

$$Tp = 5.843\ Hs^{0.375}$$
$$Hmax = 1.875\ Hs$$
$$Hc = 1.043\ Hs$$

Correlation = 0.99